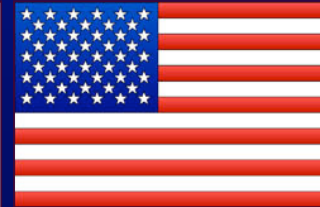


REAL-TIME FMRI: setup, image monitoring, statistics, and feedback

Ziad S Saad, PhD

SSCC / NIMH & NINDS / NIH / DHHS / USA /
EARTH



Why bother?

- Image quality control
 - Spikes, distortion, ghosting, noise, ...
 - Amount of motion
 - Operator error
- Functional localization
 - Localizer prior to main fMRI experiment for BCI or high-res imaging
 - Pre operative scanning
 - As Q/A in clinical settings or difficult / rare subject population
 - 'scan to criteria'
- Teaching
- Feedback and Biofeedback
 - Reduce motion
 - Alter/interfere brain function
 - Control of task/ stimulus computer
 - Classification/BCI
 - Signals in vegetative state

Cox, RW et al. 95,
Cohen, MS et al. 98,
Frank, J. et al 99,
Voyvodic, J. 99

Weiskopf, N. et al 04

Yang, S. et al 08

Weiskopf, N et al. 2007



Yang, S. et al. 05

deCharms. RC. et al. 04

deCharms. RC. et al. 05

Posse S. et al. 03

LaConte SM. et al. 07

Yoo S. et al. 04

Owen AM et al 06

Image Quality Control

- Image quality control
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 - Amount of motion

Cox, RW et al. 95,
Cohen, MS et al. 98,
Frank, J. et al 99,
Voyvodic, J. 99
Weiskopf, N et al. 2007

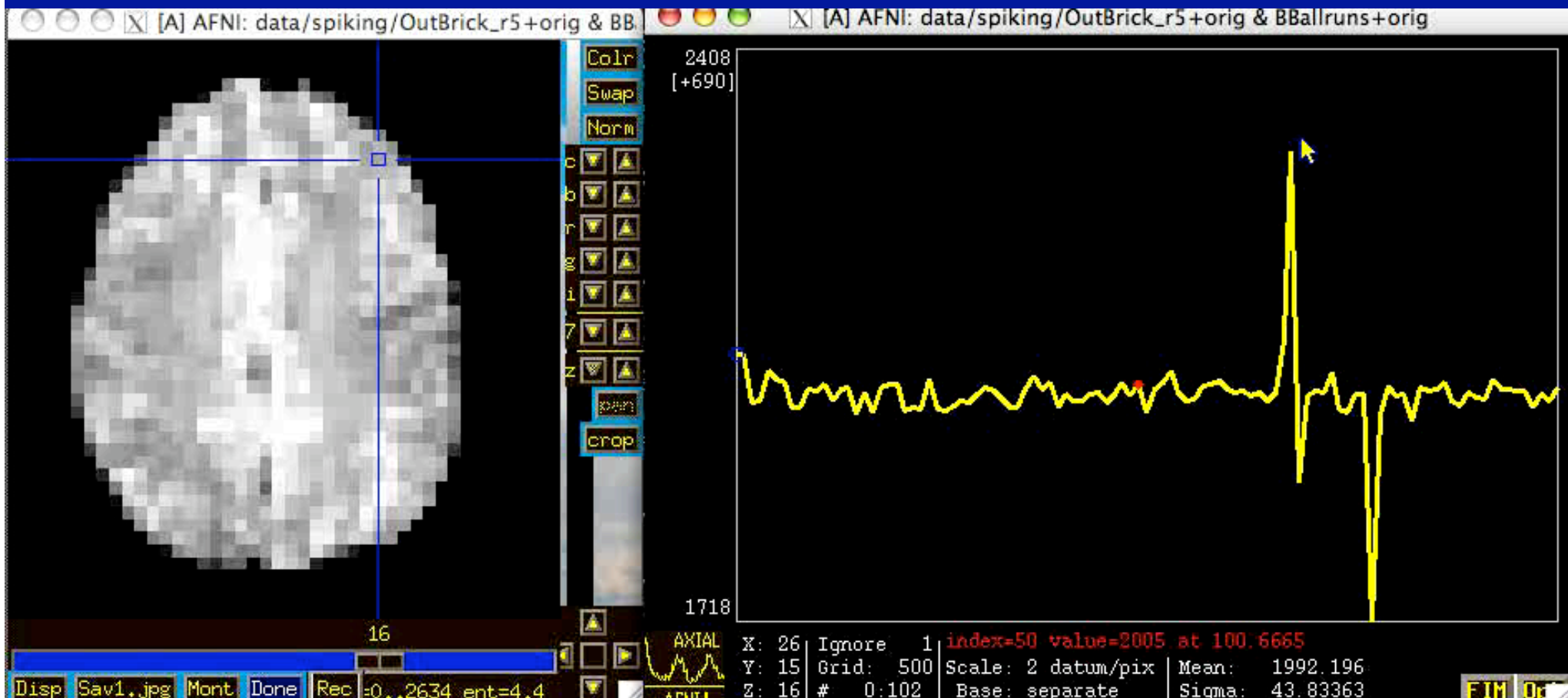


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Voyvodic, J. 99
Weiskopf, N et al. 2007

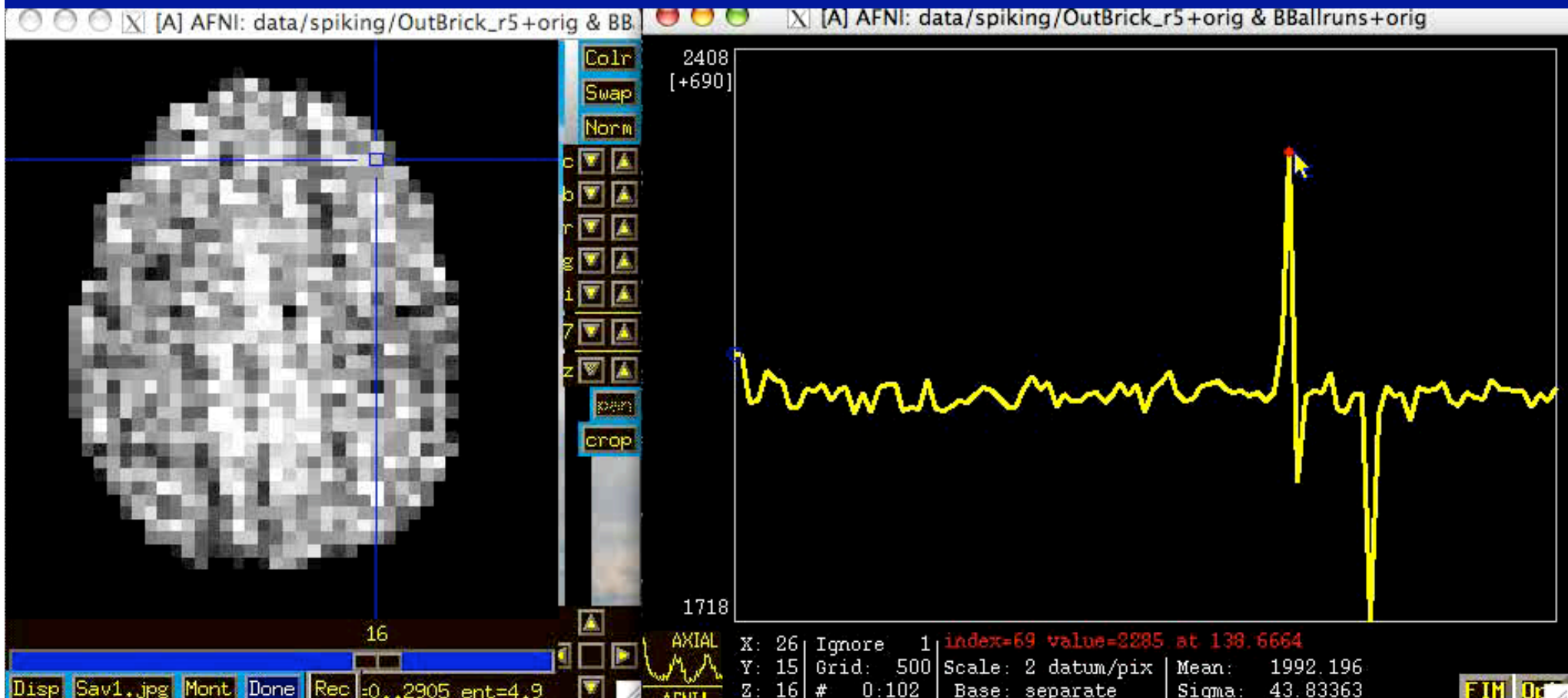
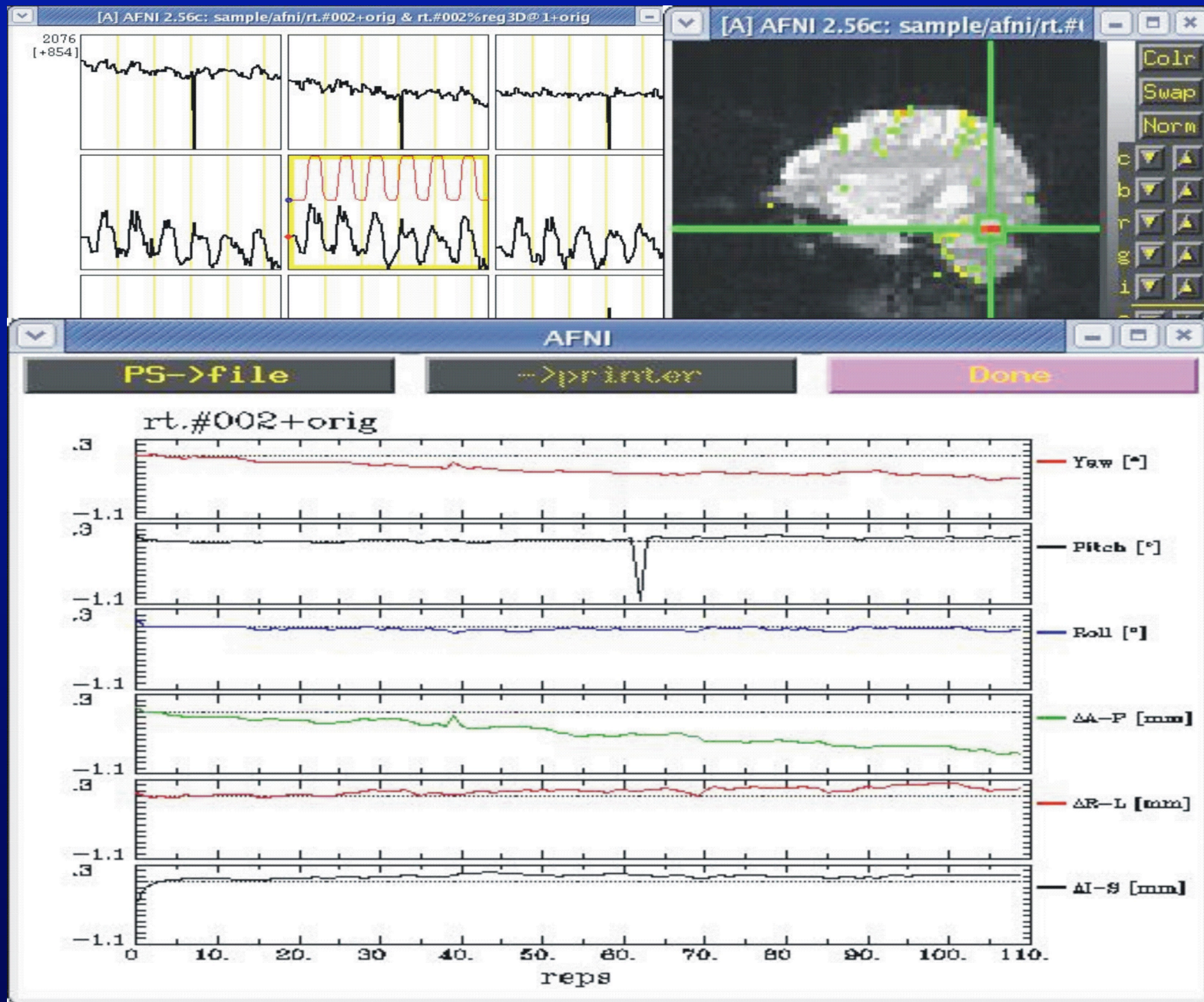


Image Quality Control



Real-time
Estimation
of
Functional
Activation

Real-time
Estimation
of
subject
movement

Image Quality Control

Real time
physiological
monitoring at
FIM/LBC/NIMH
Image courtesy of
Jerzy Bodurka

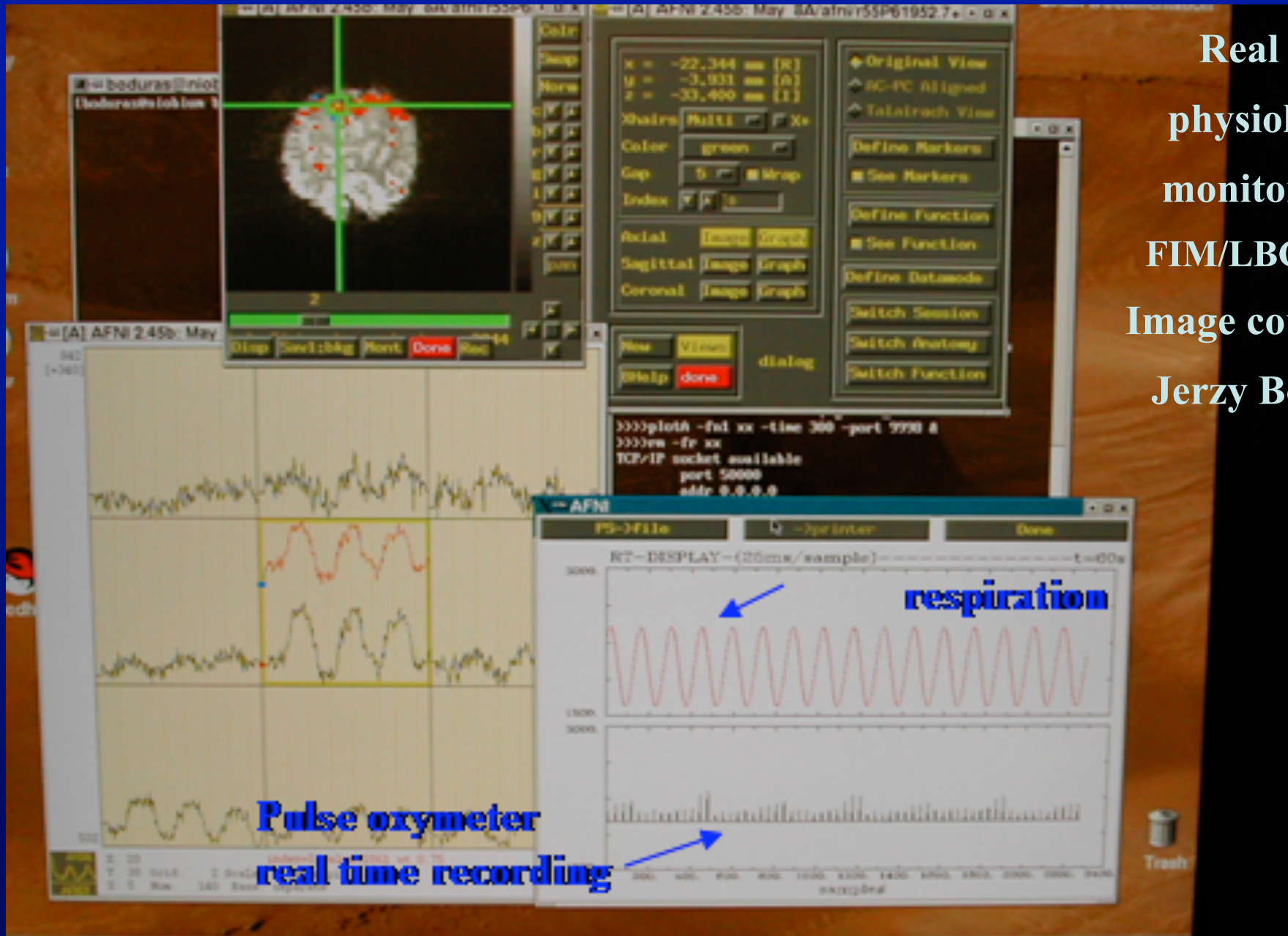


Image Quality Control

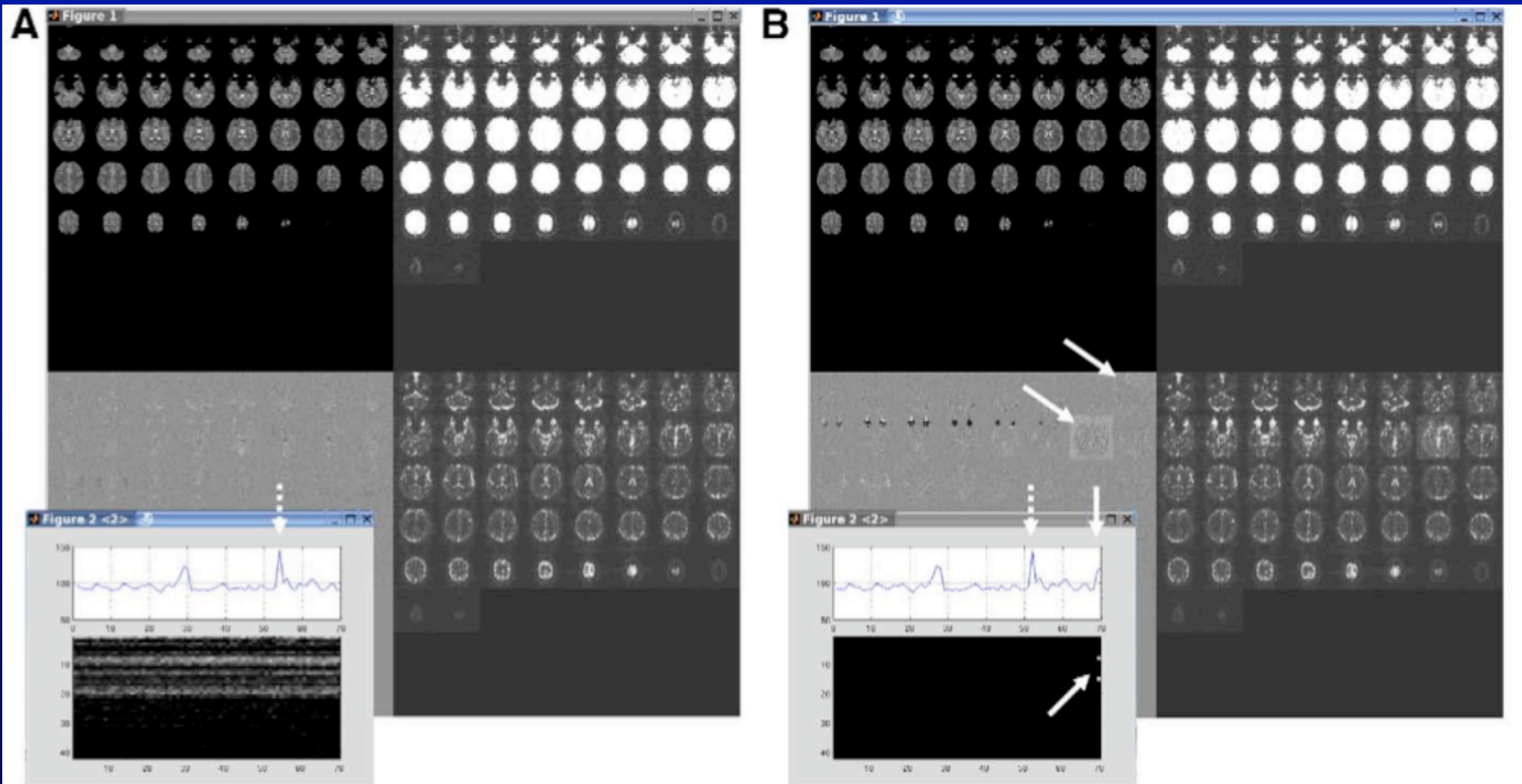


Fig. 1. From Weiskopf, N. et al. MRI 07

Reduce Motion with Feedback

- Feedback and Biofeedback
 - Reduce motion

Yang, S. et al. 08

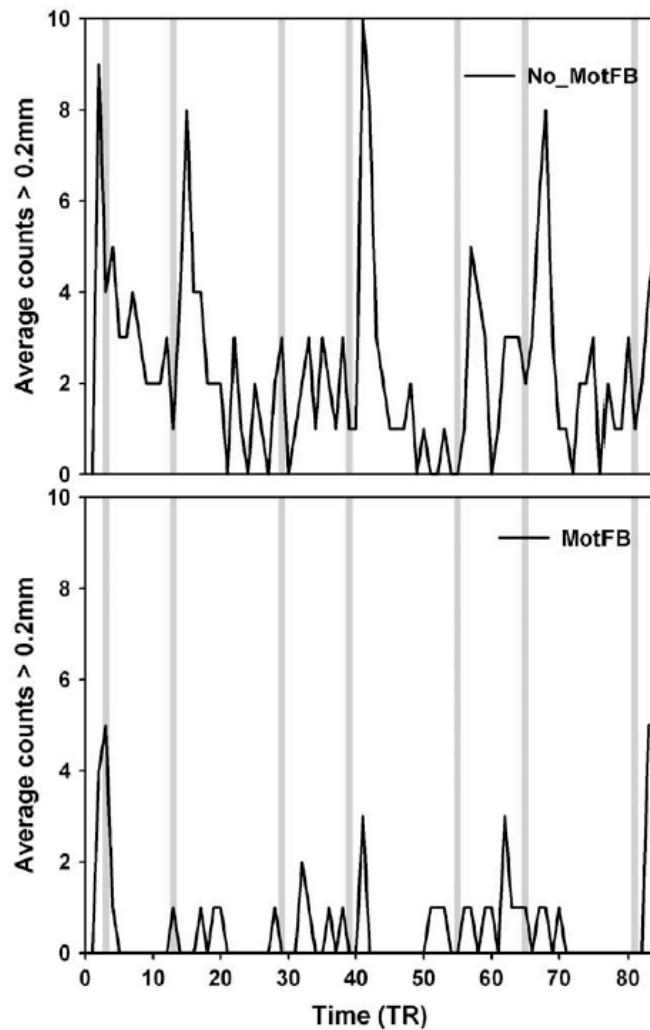


Fig.6 from Yang, S. et al. Neuroimage 05

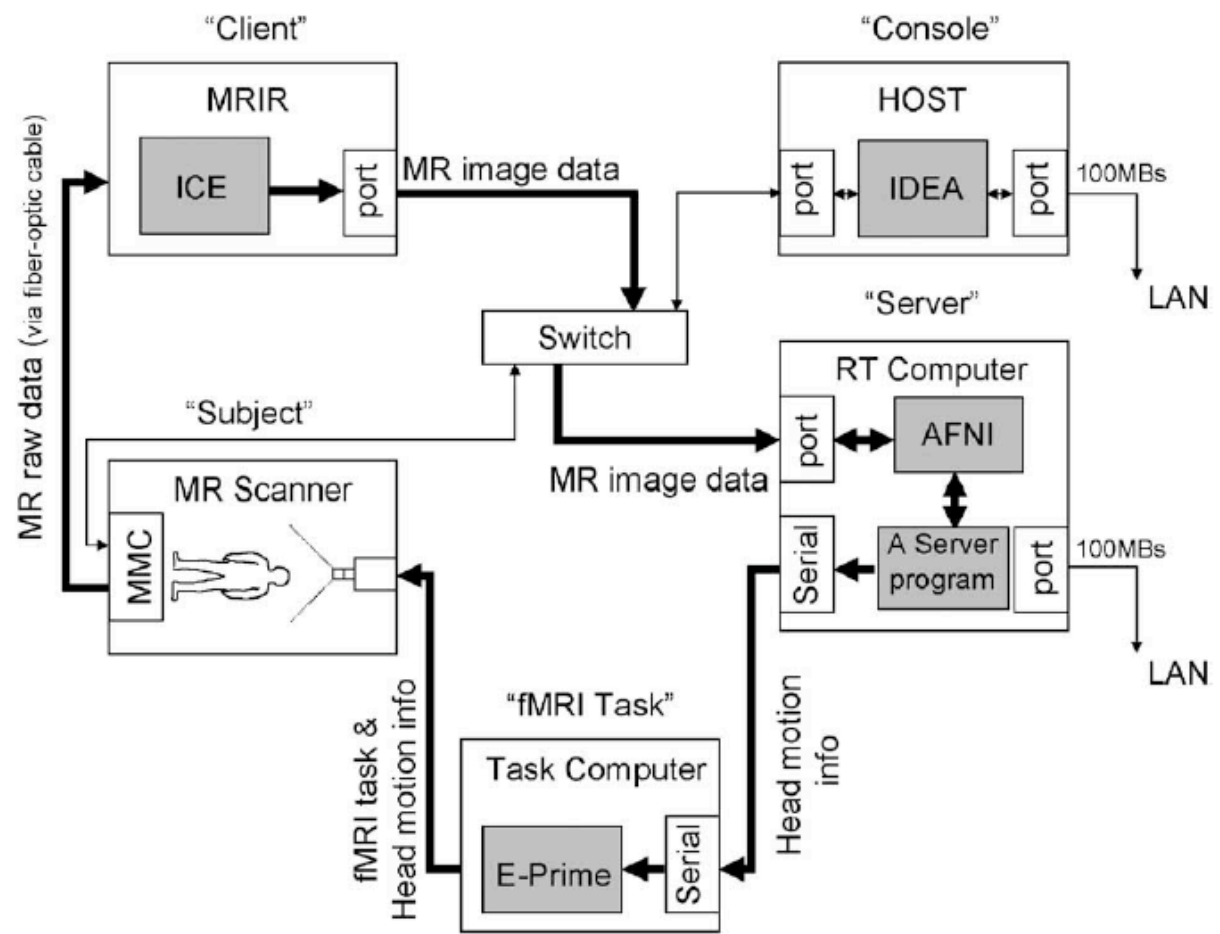


Fig. 2. Configuration of the real-time analysis system and data flow schematic.

Fig.2 from Yang, S. et al. Neuroimage 05

Activation in Vegetative State

Patient and control responses to audio instructions

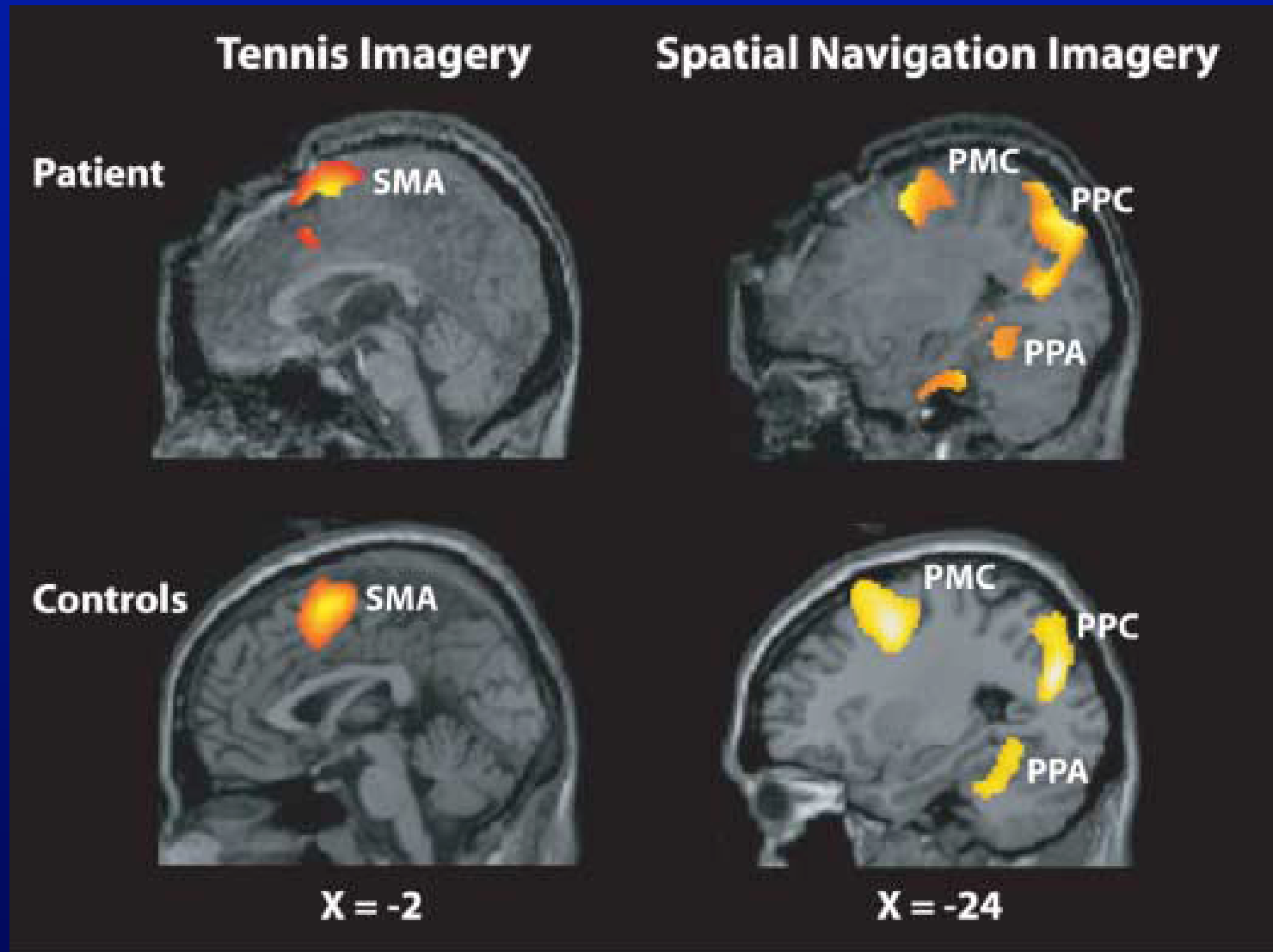
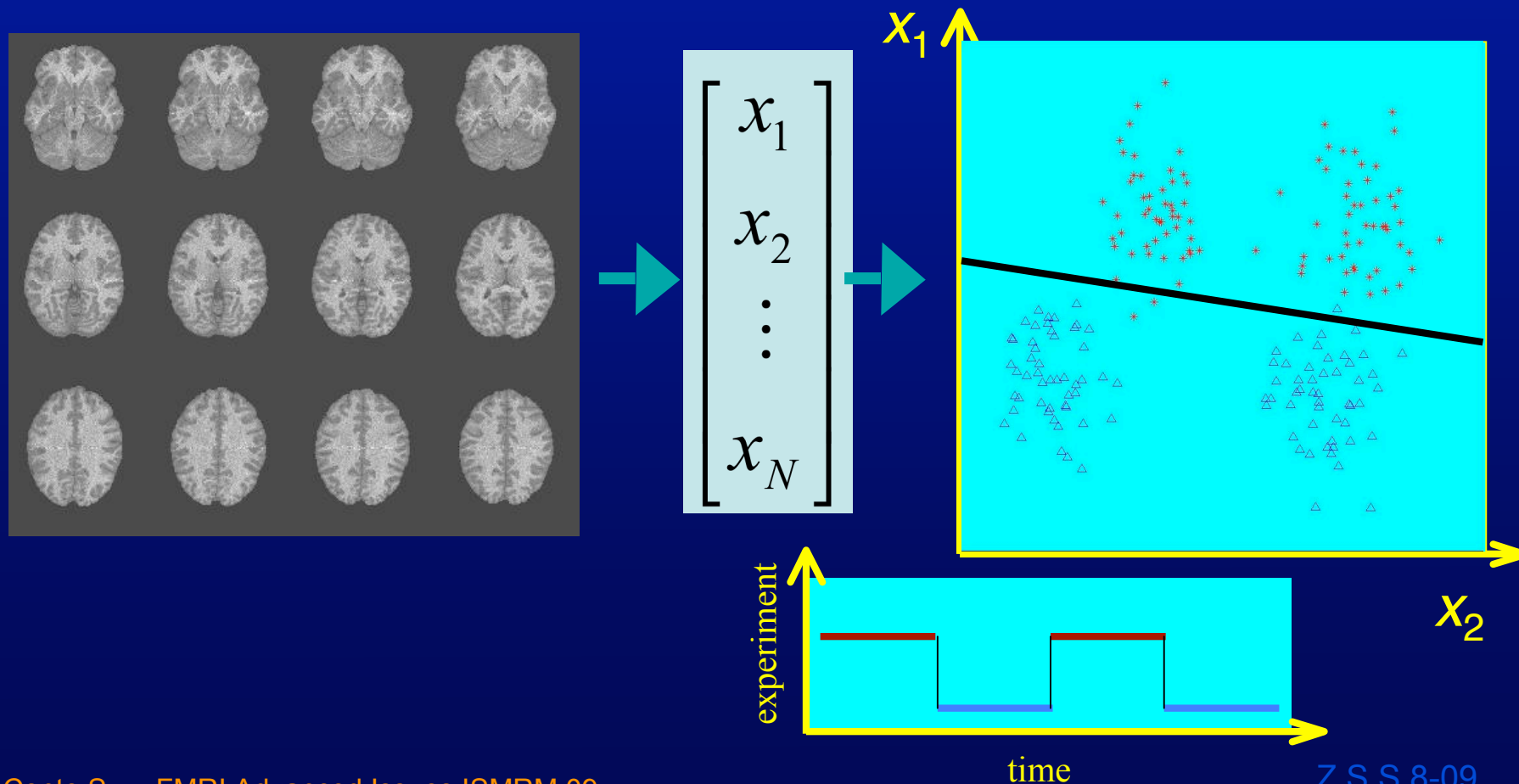


Fig.1 from Owen AM et al, Science 06

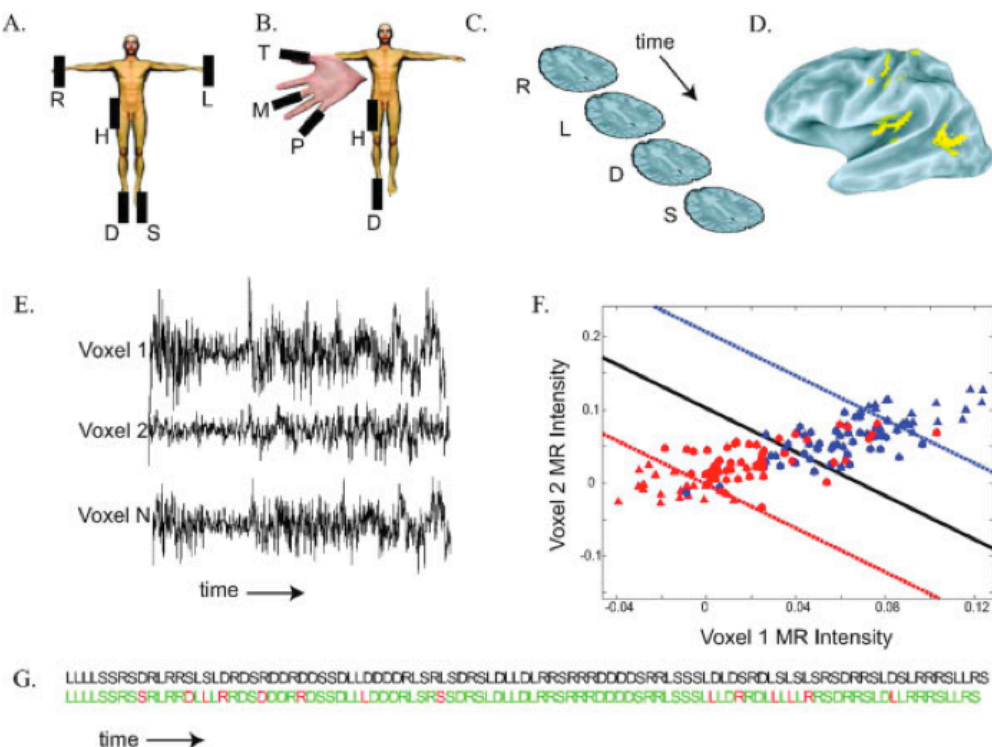
Classification

- Classification maps high dimensional pattern into a set of classes
 - This allows a complex brain activation pattern to be identified with a set of classes or brain states.
 - Useful in to providing intuitive feedback from activation of multiple areas
 - Useful for inferring brain state

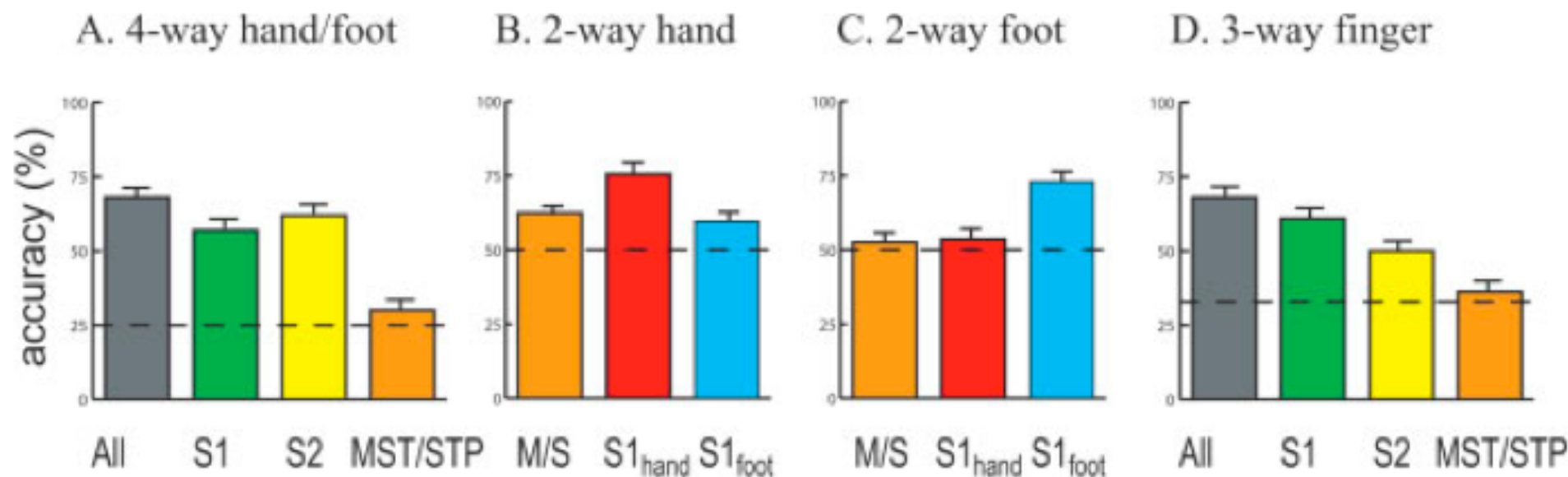


Single 2 second event

From fast
randomized event
related FMRI



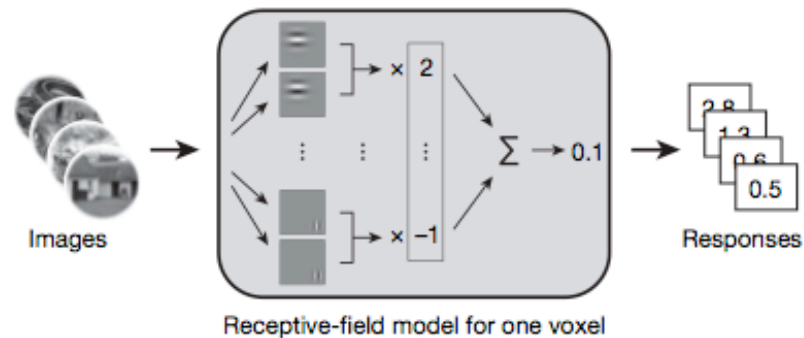
Figs.1 and 3 from
Beauchamp, M.S. et al. HBM 09



Predicting new images

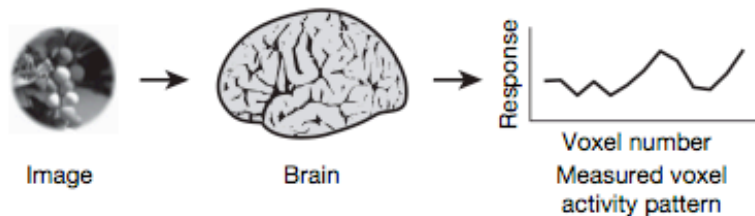
Stage 1: model estimation

Estimate a receptive-field model for each voxel

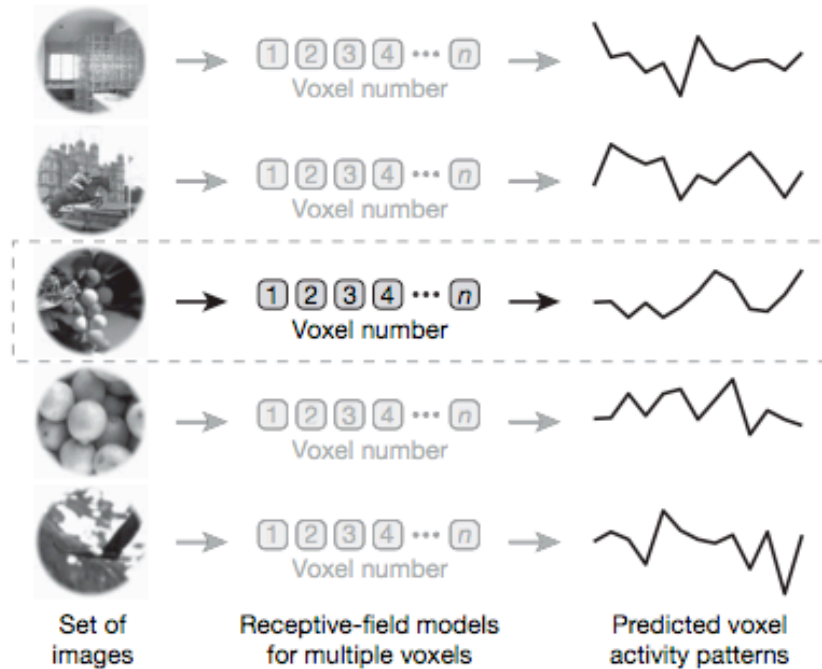


Stage 2: image identification

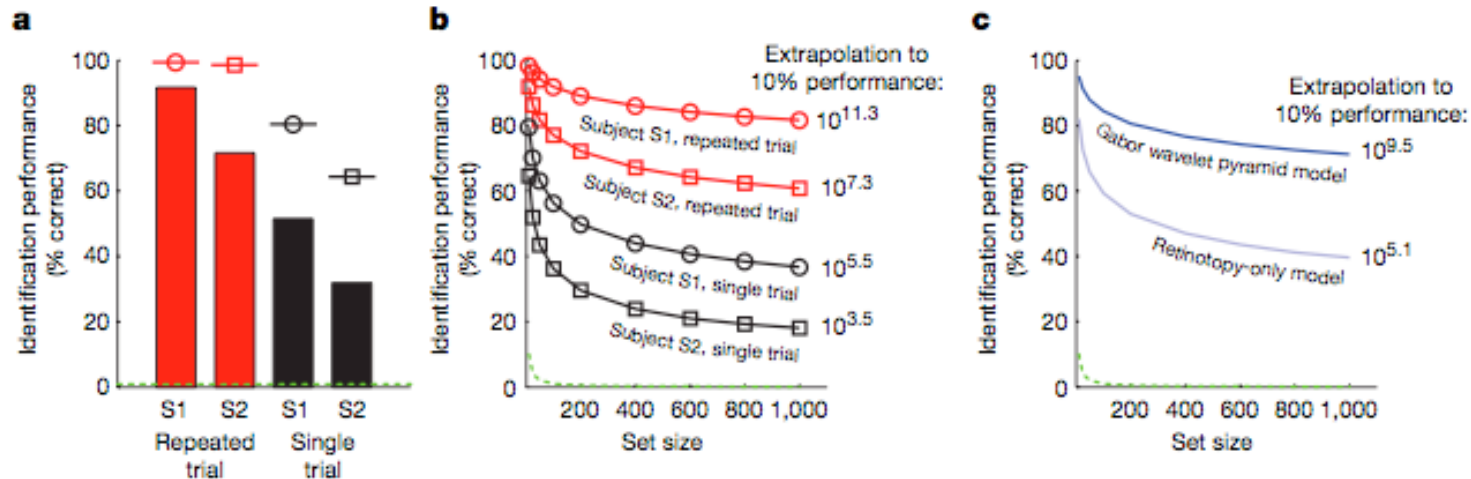
(1) Measure brain activity for an image



(2) Predict brain activity for a set of images using receptive-field models



(3) Select the image (★) whose predicted brain activity is most similar to the measured brain activity



Figs.1 and 4
from
Kay K. et al.
Nature 08

Brain Computer Interface

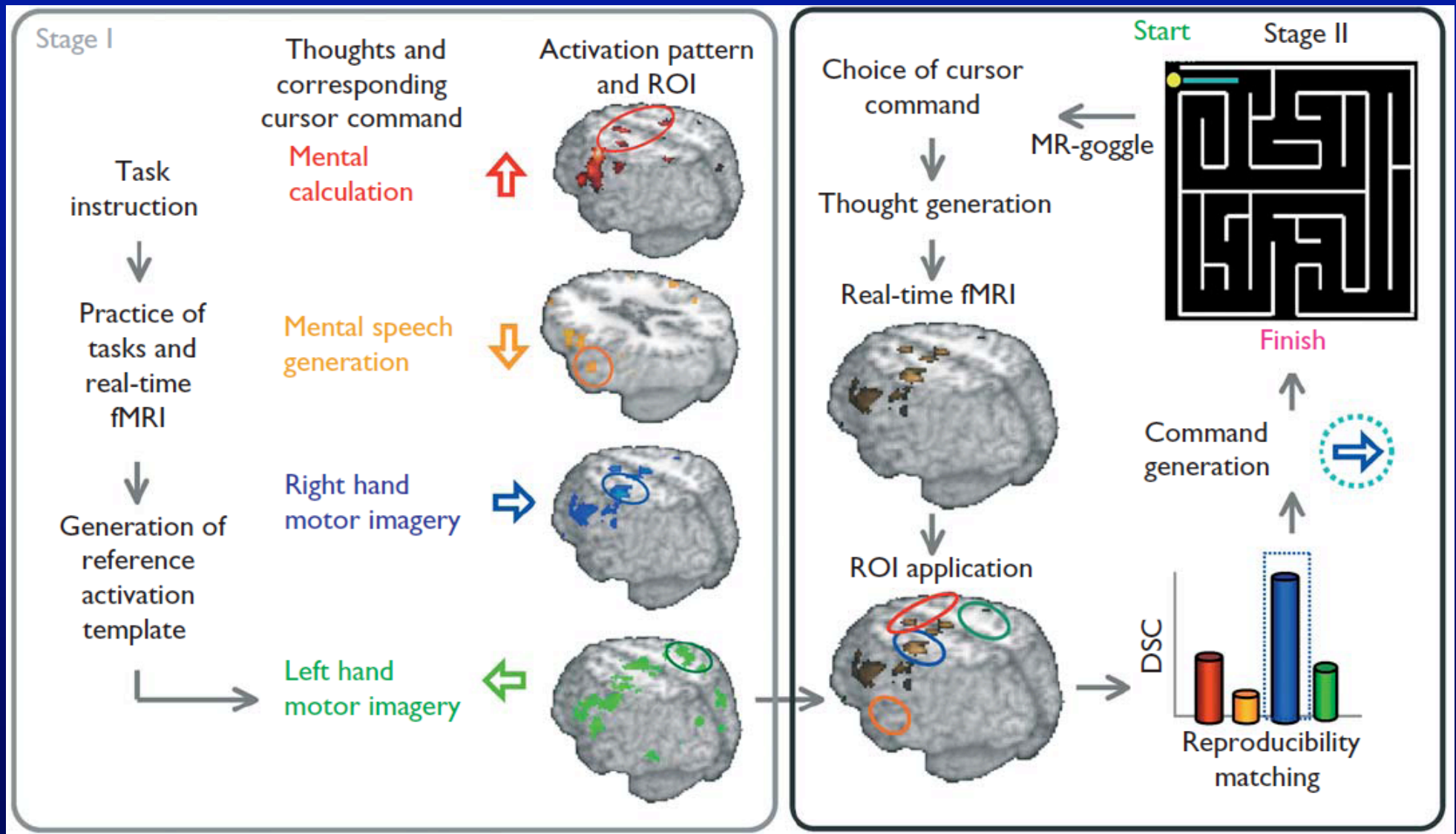
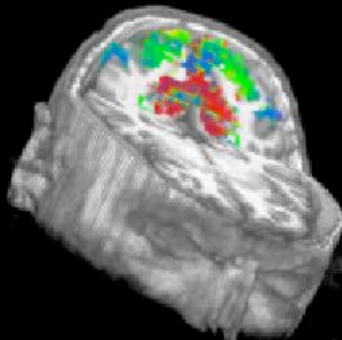
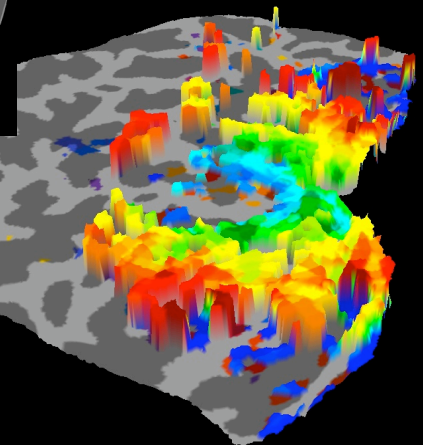
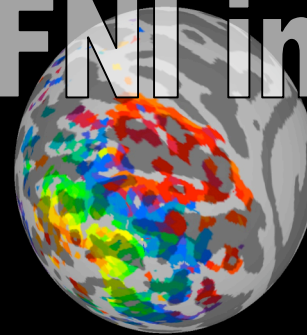
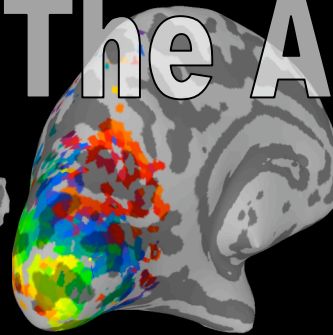
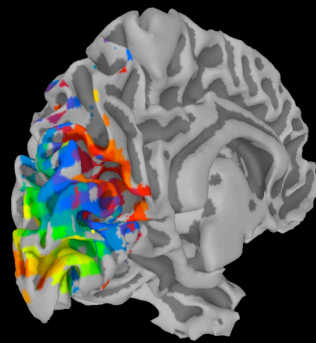
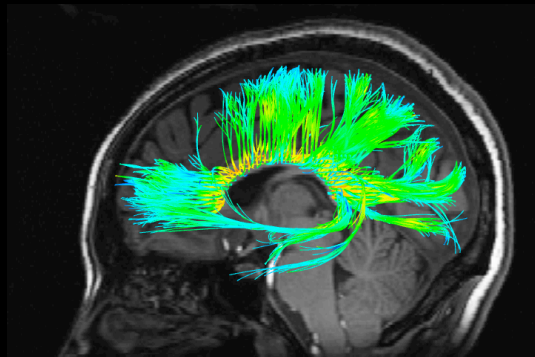


Fig.1 Yoo S. et al. Neuroreport 04

Why bother?

- Reviews:
 - Weiskopf N et al.: Real-time functional magnetic resonance imaging: methods and applications. *Magnetic Resonance Imaging* 25 (2007)
 - Yang S et al.: Real-Time Functional Magnetic Resonance Imaging and its Applications. in *Brain Mapping Research Developments*, Bakker LN ed., Nova Publishing, New Jersey (2008)
 - deCharms RC: Applications of real-time fMRI. *Nature Reviews Neuroscience* 9 (2008)
 - deCharms RC: Reading and controlling human brain activation using real-time functional magnetic resonance imaging. *Trends in Cognitive Sciences* 11 (2007)

The AFNI interface



[X] [A] AFNI: suma_demo/afni/DemoSubj_SurfVol_Alnd_Exp+orig & DemoSubj_EccExpavir.DEL+orig

[Order: RAI=DICOM]
 x = 0.500 mm [L]
 y = 83.500 mm [P]
 z = -0.500 mm [I]

Xhairs ☐ Multi ☐ X+
 Color black ☐
 Gap 5 ☐ Wrap
 Index

Axial
 Sagittal
 Coronal

left=Right byte=0..252 ent=5,18

Original View
☒ AC-PC Aligned
☒ Talairach View

☐ See Markers

☒ See Overlay

Corr Inten Options
 1.00
 0.95
 0.90
 0.85
 0.80
 0.75
 0.70
 0.65
 0.60
 0.55
 0.50
 0.45
 0.40
 0.35
 0.30
 0.25
 0.20
 0.15
 0.10
 0.05

☒ Ulay underlay
☒ Olay underlay
 Ulay #0 #0
 Olay #0 Delay
 Thr #2 Corr Coef

Ulay
 Olay
 Thr -
☒ auto

[+++++ nearby Atlas structures +++++]
 Focus point (LPI)=
 -3 mm [L], -80 mm [P], 12 mm [S] {T-T Atlas}
 -3 mm [L], -83 mm [P], 9 mm [S] {MNI Brain}
 -3 mm [L], -88 mm [P], 20 mm [S] {MNI Anat.3}

Atlas TI_Daemon: Talairach-Tournoux Atlas
 Focus point: Left Cuneus
 -AND- Left Brodmann area 17
 Within 2 mm: Left Brodmann area 18
 Within 5 mm: Left Brodmann area 23
 Within 7 mm: Left Lingual Gyrus
 -AND- Left Brodmann area 30

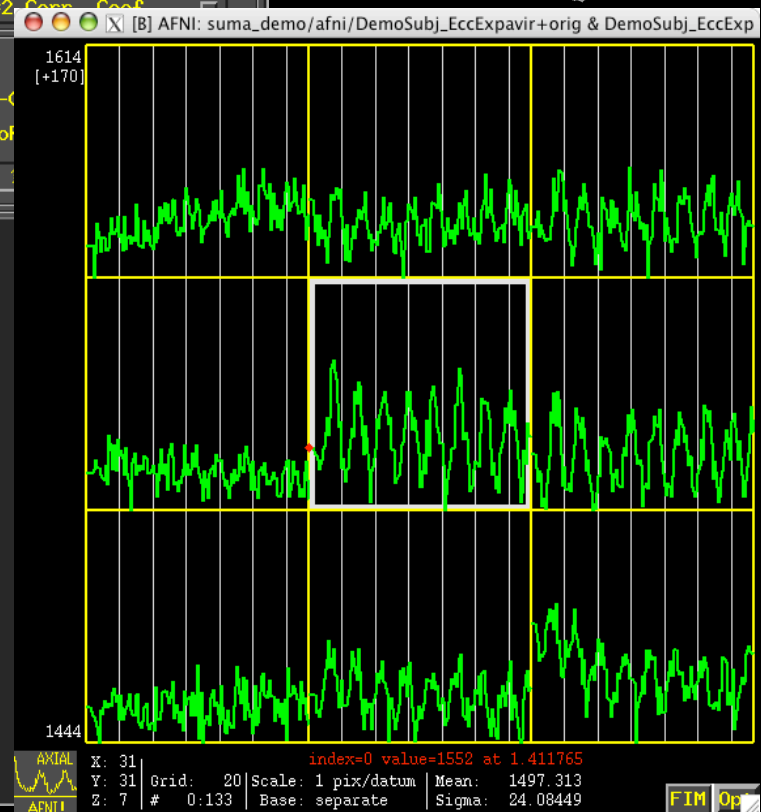
Atlas CA_N27_MPM: Cytoarch. Max. Prob. Maps (N27)
 Focus point: hIP1
 Within 3 mm: Amyg. (SF)

Atlas CA_N27_ML: Macro Labels (N27)
 Focus point: Left Calcarine Gyrus
 Within 1 mm: Left Cuneus
 Within 7 mm: Right Cuneus

Atlas CA_N27_PM: Cytoarch. Probabilistic Maps (N27)
 Focus point: Area 17 (p = 0.50)
 -AND- Area 18 (p = 0.60)

Atlas CA_N27_LR: Left/Right (N27)
 Focus point: Left Brain
 Within 6 mm: Right Brain

.3786



The AFNI interface

- Slice Viewer
- Graphing time series
- Function
- Plugins
- whereami

The players

Scanner

Real Time Setup

RT Plugin

Image Monitor

AFNI

Plugin

Real Time Receiver

Stimulus Display

The players

Scanner

Real Time Setup

RT Plugin

Image Monitor

AFNI

Plugin

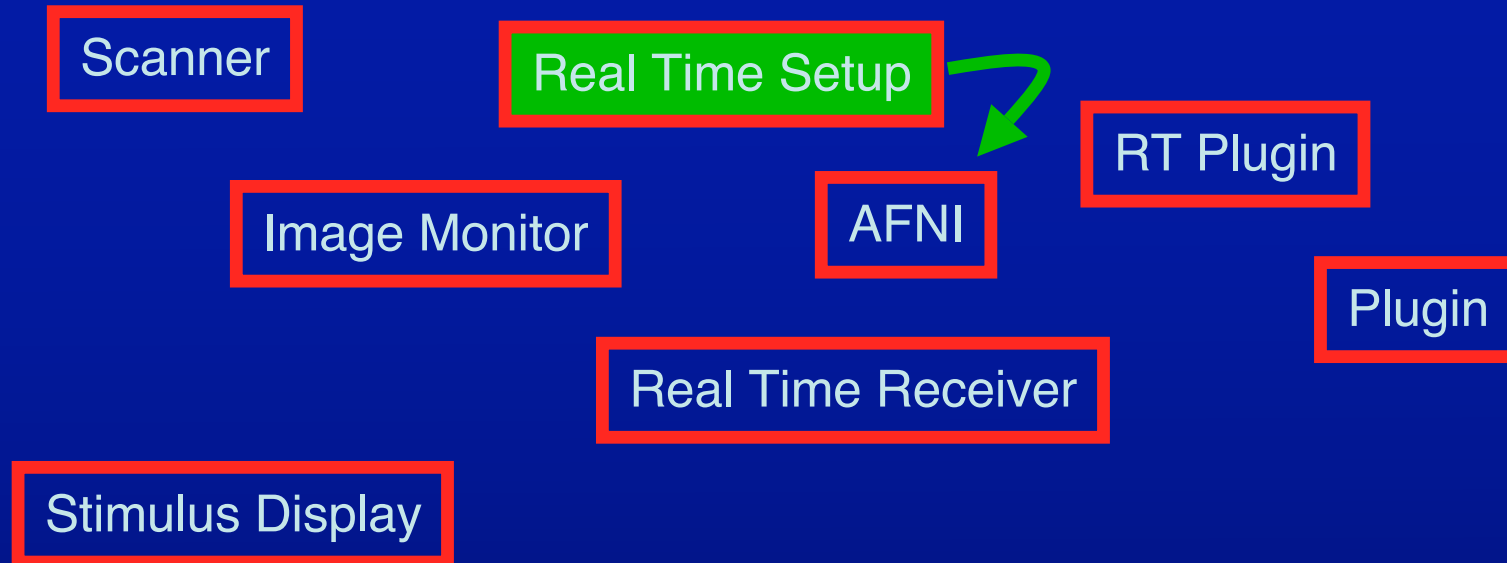
Real Time Receiver

Stimulus Display

- Scanner
 - A user-supplied machine to acquire and reconstruct images in real time



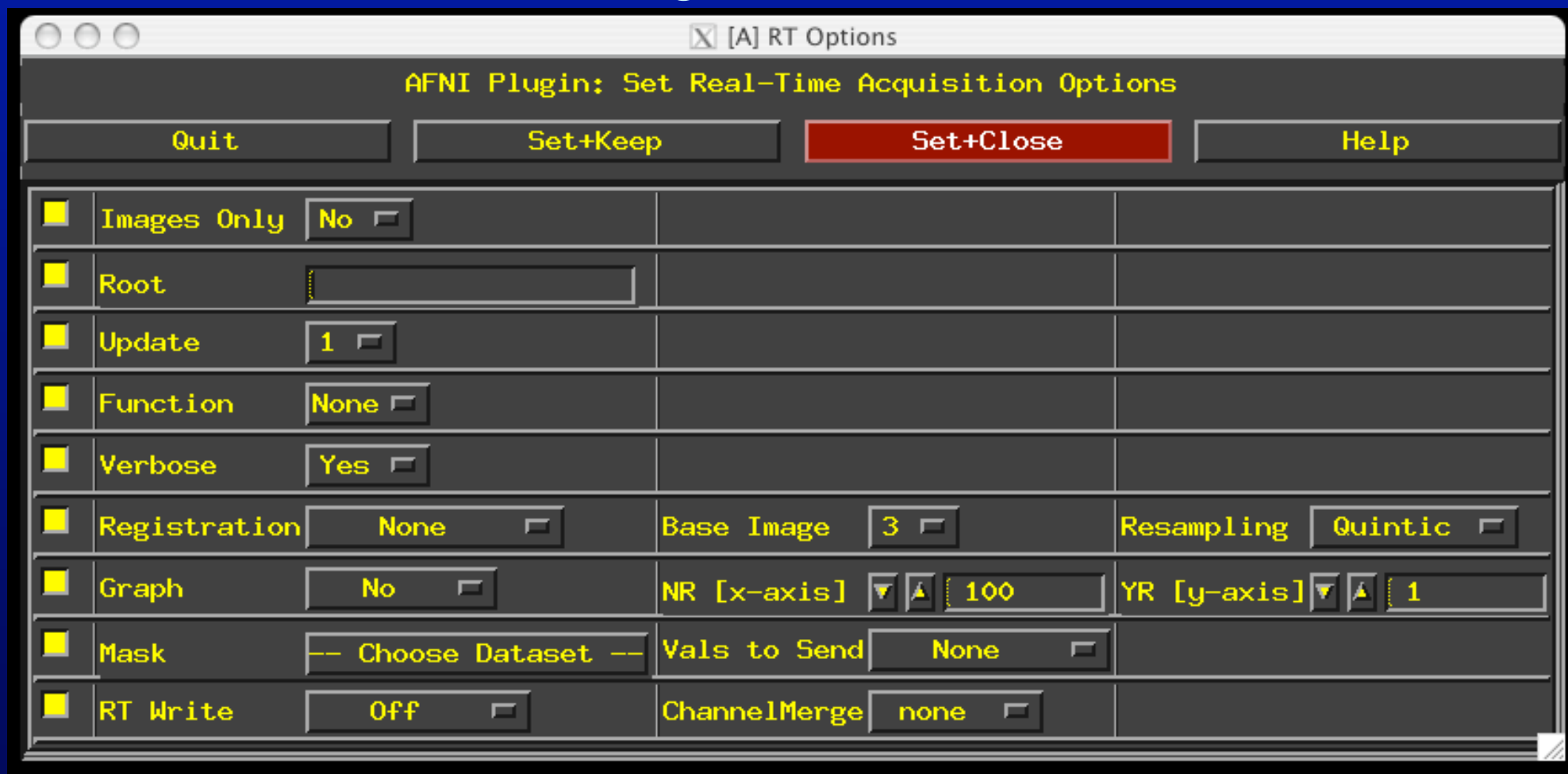
The players



- Real Time Setup
 - A user-supplied set of commands that tell AFNI what to do with incoming data
 - Can be done from shell commands or from within C code
 - Communicates with AFNI through TCP/IP socket
 - Sets up ROIs for AFNI*

Setting up AFNI's RT plugin

- Manually
 - Good for learning and demo

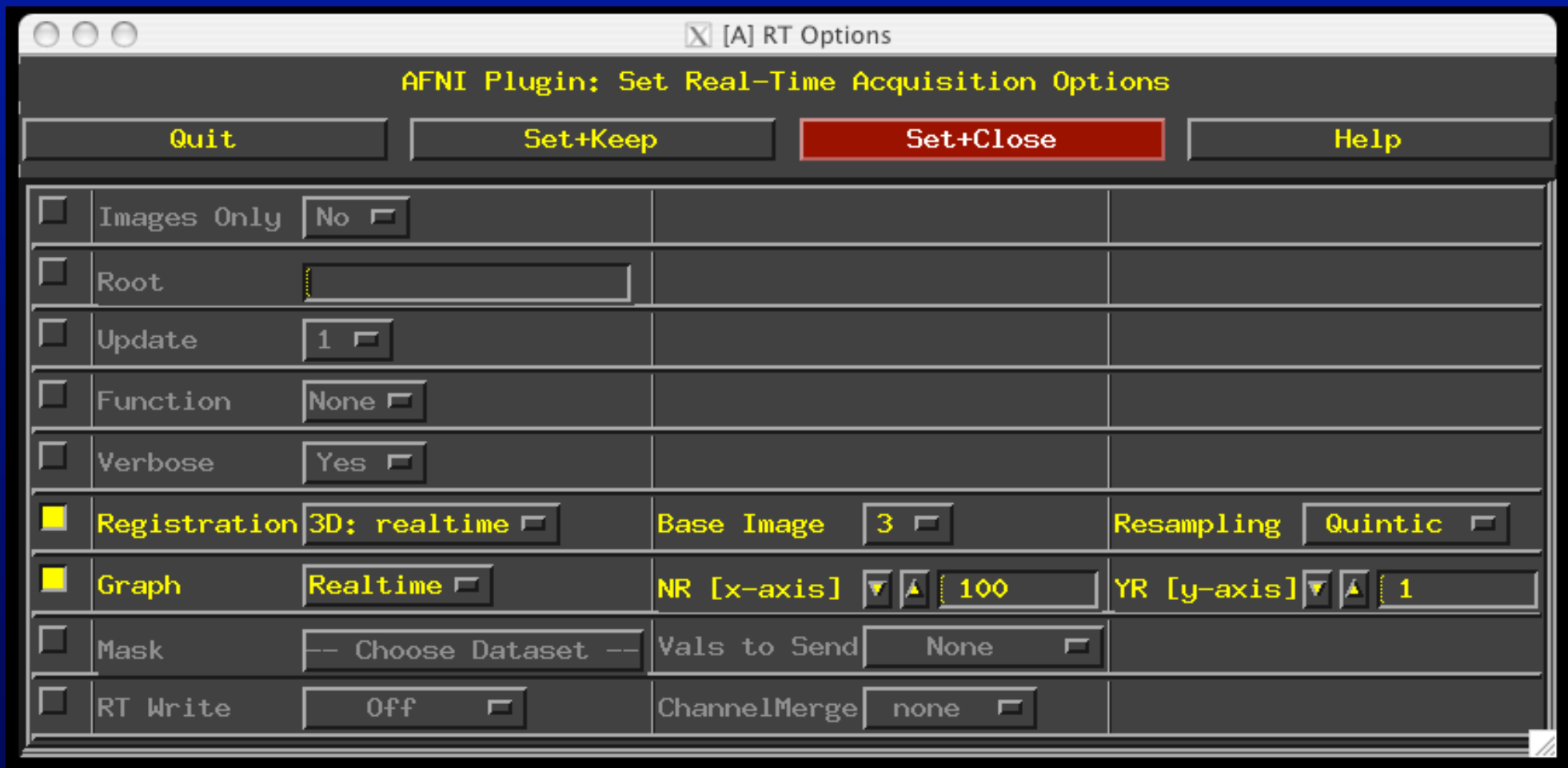


Setting up AFNI's RT plugin

- Via Environment Variables

setenv AFNI_REALTIME_Registration 3D:_realtime

setenv AFNI_REALTIME_Graph Realtime



Setting up AFNI

- Manually
- Environment variables
 - See README.environment (~250 variables)
- Layout files
 - Size and position windows just so
- Via `plugout_drive`
 - Details will follow
- Via *image_monitor* module -drive options
 - drive_wait 'OPEN_WINDOW axialgraph keypress=A'
 - drive_afni 'CLOSE_WINDOW axialimage'

Demo time

- Motion monitoring
- Motion & function

ROI selection options

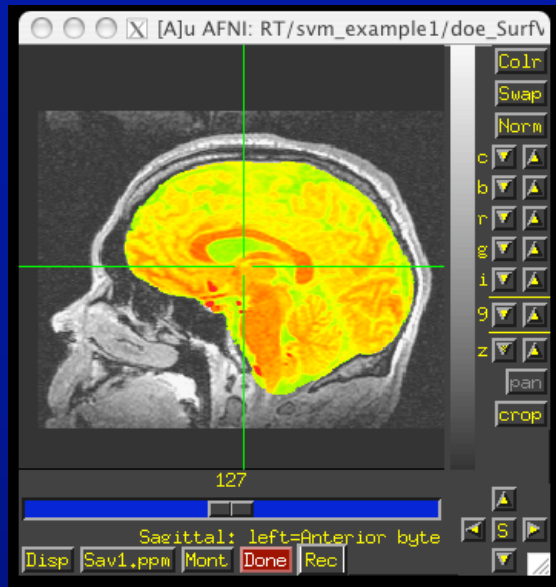
- Standard atlases
 - TT_Daemon :
 - Created by tracing Talairach and Tournoux brain illustrations.
 - Contributed by Jack Lancaster and Peter Fox of RIC UTHSCSA
 - CA_N27_MPM, CA_N27_ML, CA_N27_PM :
 - Anatomy Toolbox's atlases, some created from cytoarchitectonic
 - studies of 10 human post-mortem brains
 - contributed by Simon Eickhoff, Katrin Amunts and Karl Zilles of IME, Julich,
- FreeSurfer, subject-based
- Functional localizer
- Etc.

Standard-space atlas ROI selection

```
@fast_roi -region CA_N27_ML::Hip \  
          -region CA_N27_ML::Amygda \  
          -base TT_N27_r2+tlrc. \  
          -anat doe_SurfVol_Alnd_Exp+orig. \  
          -roi_grid blur_vr_run1_motor_AFB003+orig. \  
          -prefix hip_amy -time
```

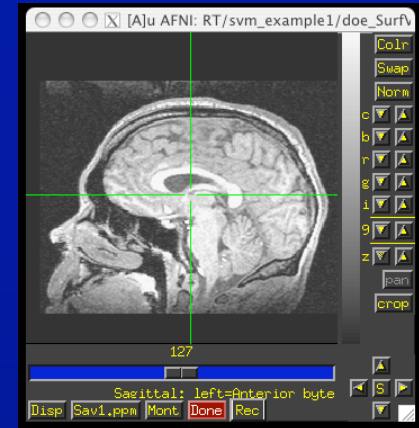
- less than 1min including skull stripping and xform to TLRC
- A couple of seconds for generating more ROIs

Atlas-based ROIs



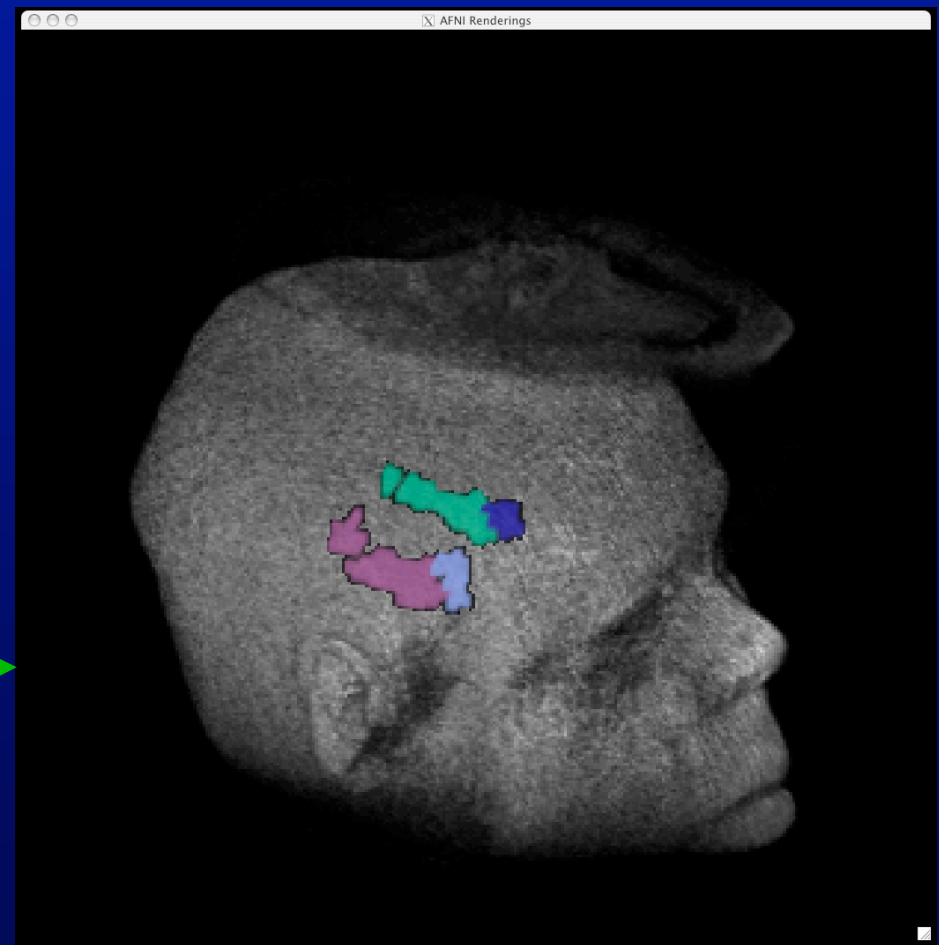
1- Strip skull

2- Find xform to atlas space
(about 40 secs, 2.5GHz cpu)

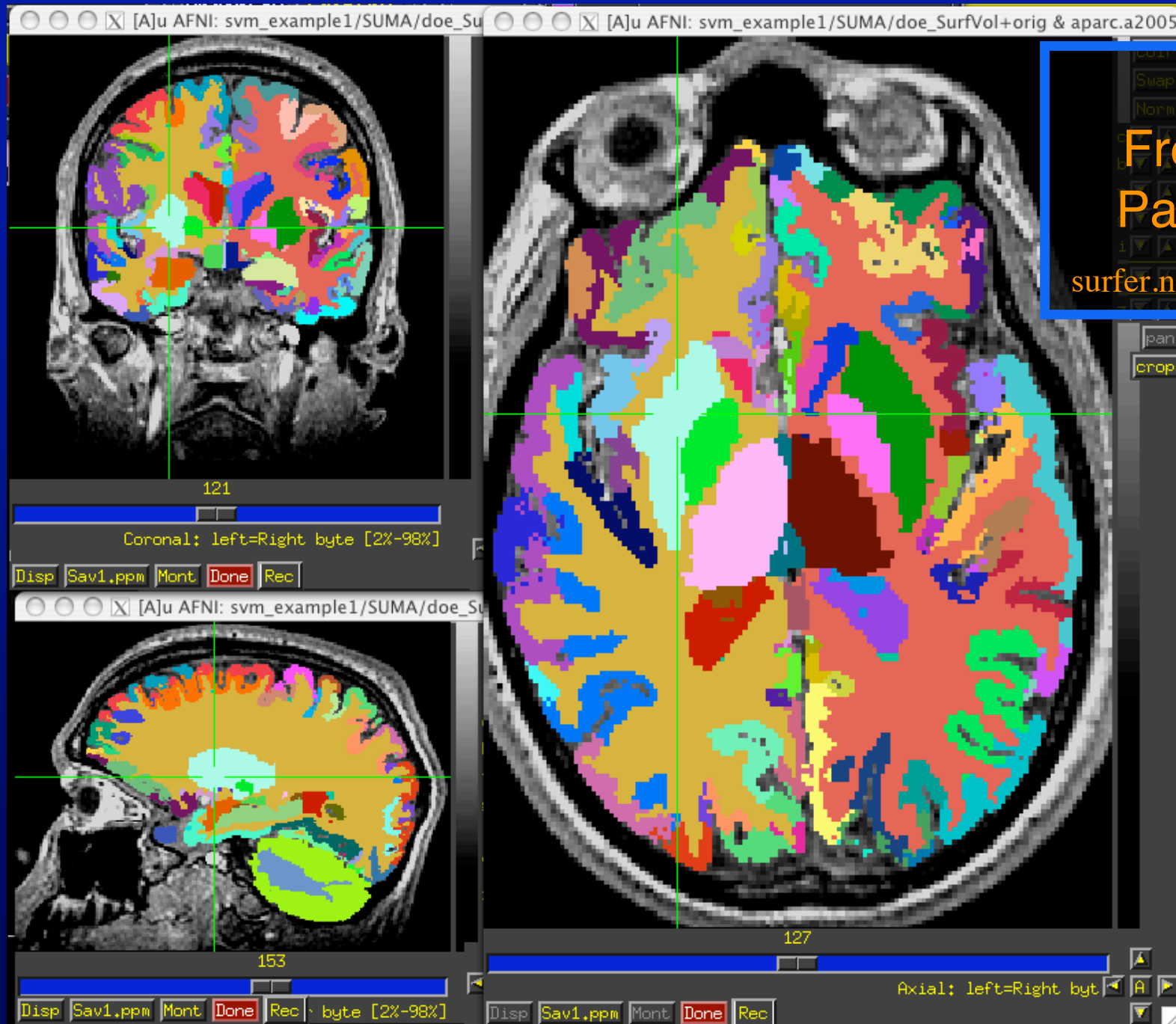


3- Identify ROIs

4- Xform ROIs to native space
(about 2 seconds)



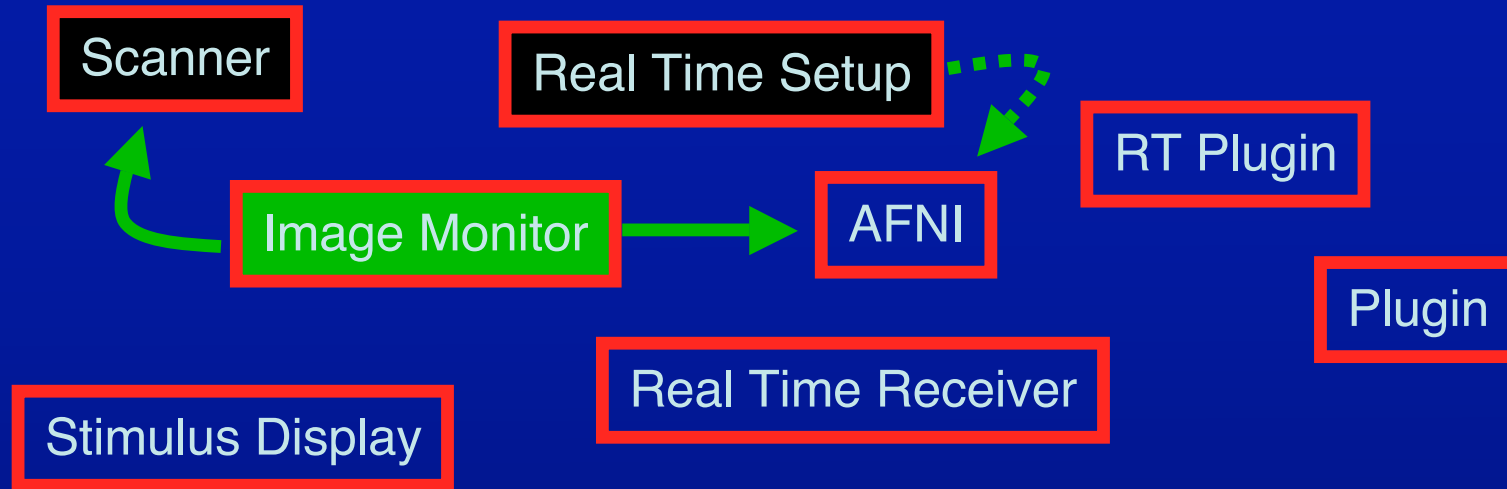
Subject-based Anatomical ROIs



From
FreeSurfer's
Parcellations

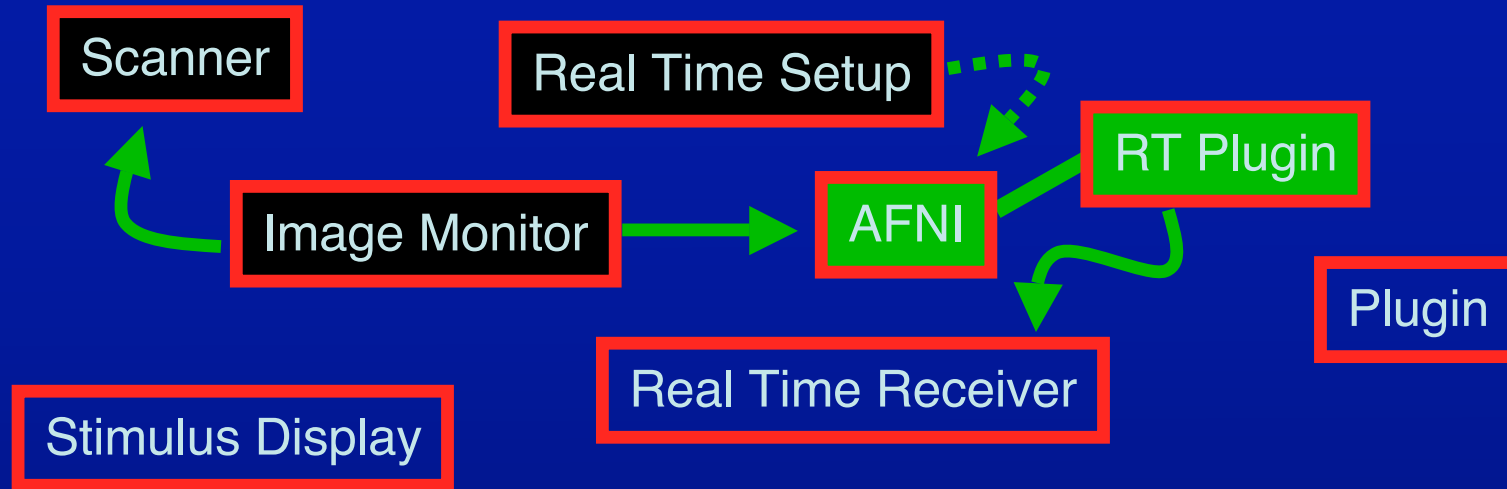
surfer.nmr.mgh.harvard.edu

The players



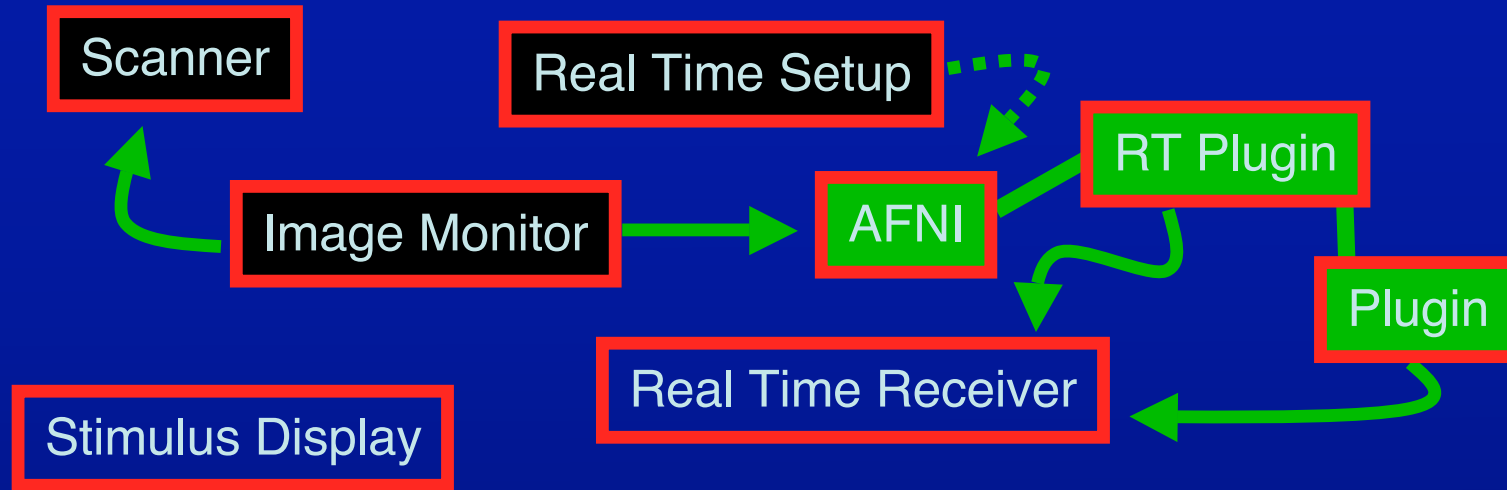
- Image Monitor
 - An AFNI- or user- supplied program to wait for new images
 - AFNI-supplied programs monitor files only:
 - Imon (Monitors GE's old dreaded I files)
 - Dimon (Monitors GE's DICOM images)
 - RTfeedme (Breaks up timeseries dataset and sends it to AFNI)
 - User-supplied programs usually interface with scanner software
 - SIEMENS TRIO/ALLEGRA via functors (S. LaConte BCM, E. Stein NIDA)
 - Often only program that runs on scanner computer
 - Image Monitor sends new images or volumes to AFNI over TCP/IP socket

The players



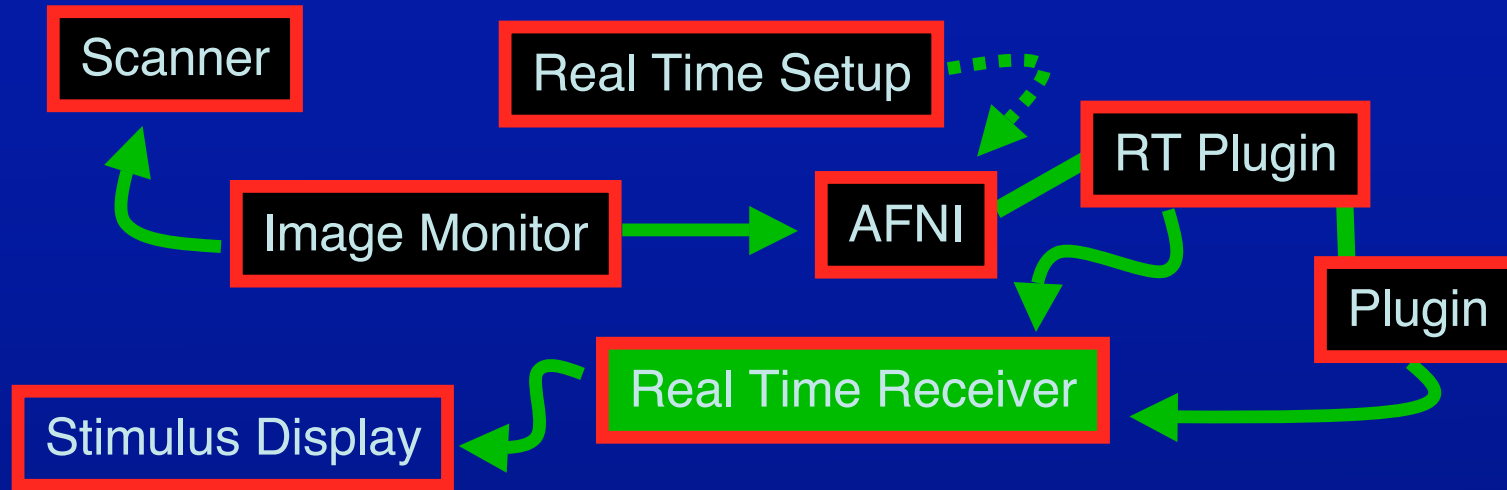
- AFNI/RT plugin take incoming images/volumes and processes them per the setup instructions
 - Assemble images/volumes into time series
 - Perform image registration
 - Perform (multi*) linear regression
 - Send results to Real Time Receiver through TCP/IP socket
 - Raw, volume registered, or residual volume*
 - ROI based results
 - Send raw or processed volumes to plugins registered to receive them
 - Much faster than TCP/IP (just a data pointer is passed)
 - Plugins can also communicate with Real Time Receiver

The players



- AFNI/RT plugin take incoming images/volumes and processes them per the setup instructions
 - Assemble images/volumes into time series
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 - Plugins can also communicate with Real Time Receiver

The players



- Real Time Receiver (e.g. serial_helper.c or realtime_receiver.py)
 - AFNI- or User- supplied application that expects incoming data from AFNI and acts on it
 - Motion parameters
 - ROI-based data, all values or just average
 - Entire volumes of raw, or preprocessed data
 - Data from any RT plugin such as 3dsvm
 - Process incoming data to your liking
 - Optionally forward results to Stimulus Display either by serial connection, or TCP/IP*

Image Monitor (Dimon)

Dimon:

- monitor acquisition of Dicom or GE-Ifiles
 - optionally write to3d script for creation of AFNI datasets
 - optionally send volumes to afni's realtime plugin
-

find first volume (wait forever, scanning may not have started)

wait for volume:

check every 2 seconds or every -sleep_init ms

check slices to see if a volume is acquired

once found:

note grid, orientation, byte order, etc.

if realtime:

comm: open link

try to open TCP channel to afni RT plugin

check whether channel is ready for data

comm: send control info

send acquisition style (2D+zt), zorder, time pattern,
TR, FOV, grid, datum, orientation, origin, etc.

comm: send volume

Image Monitor (Dimon), part II

set signal handlers, and note between-volume sleep time

for each found volume

while no new volume is yet found

check whether the scanner has stalled (run cancelled?)

sleep for one TR, or -sleep_vol ms, or -sleep_frac fraction of TR

if this is a new run

comm: send "end of (previous) run" message

track volume statistics

check orientation

comm: if connection not yet established, send control info

comm: send volume

upon termination (ctrl-c or -quit and no more data)

show run statistics

possibly create to3d script

comm: terminate connection

Plug realtime

plug_realtime:

- init: register work process with afni (to be called regularly)

- plugin main: sets plugin control variables

main work process: asynchronously from main afni loop

- if new connection, initialize

- if data is bad or no new data after timeout

 - write vol. to disk, plot final motion params, comm:close

- if new data: warn user and process

 - process control info: TR, grid, orientation, DRIVE comds., etc.

 - prepare to receive data from multiple channels

 - setup new dataset

- if done with data: finish_dataset and cleanup

- while there is data to read

 - store into images

 - if we have a full volume

 - add volume to dataset

 - possibly register volume to base

 - update registration graph

 - possibly run regression

 - comm: compute and send TR data to realtime receiver

Realtime_receiver.py

set signal handlers to close all ports on exit

open incoming socket and wait for connection...

forever:

 process one run

 wait for the real-time plugin to talk to us

 check magic HELLO for type/amount of data to receive:

 only motion

 motion plus N ROI averages

 motion plus N voxel values (with coordinates, etc.)

 open outgoing serial port

 while no run termination, process one TR

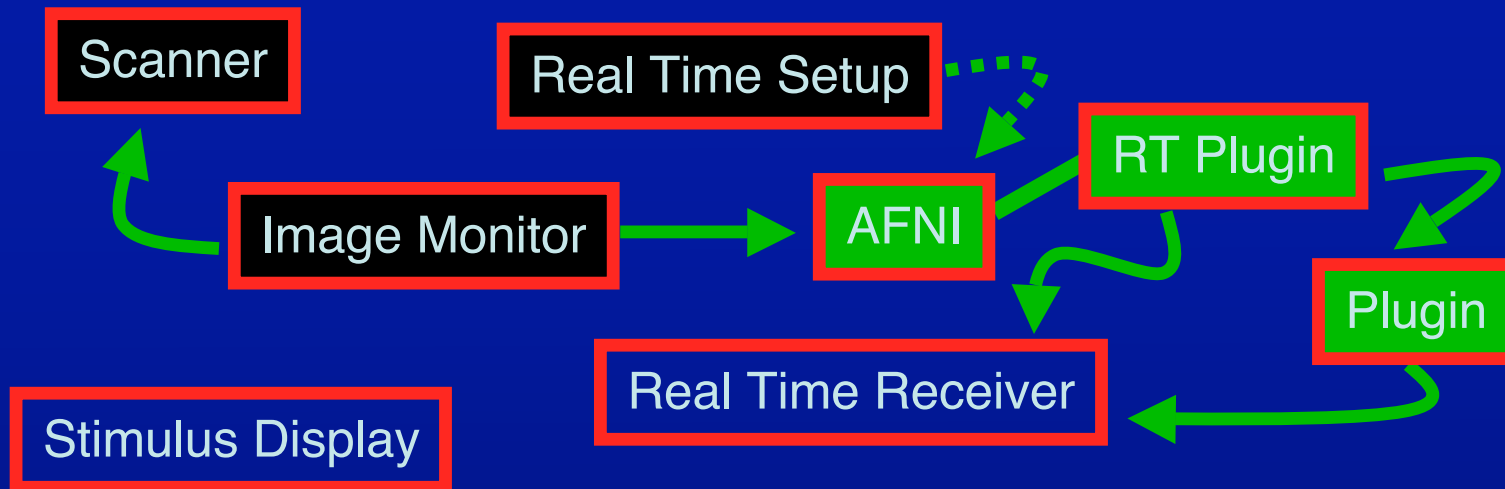
 read incoming TCP data

 compute outgoing results

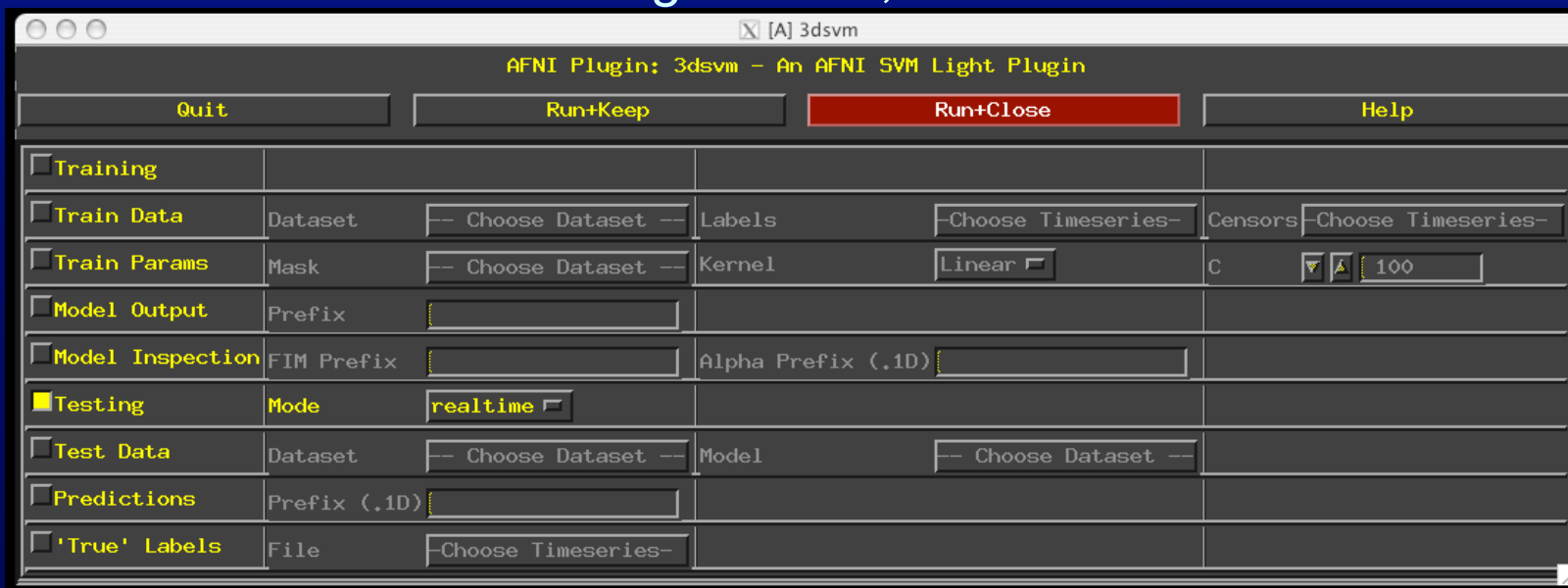
 write to serial port

close data ports

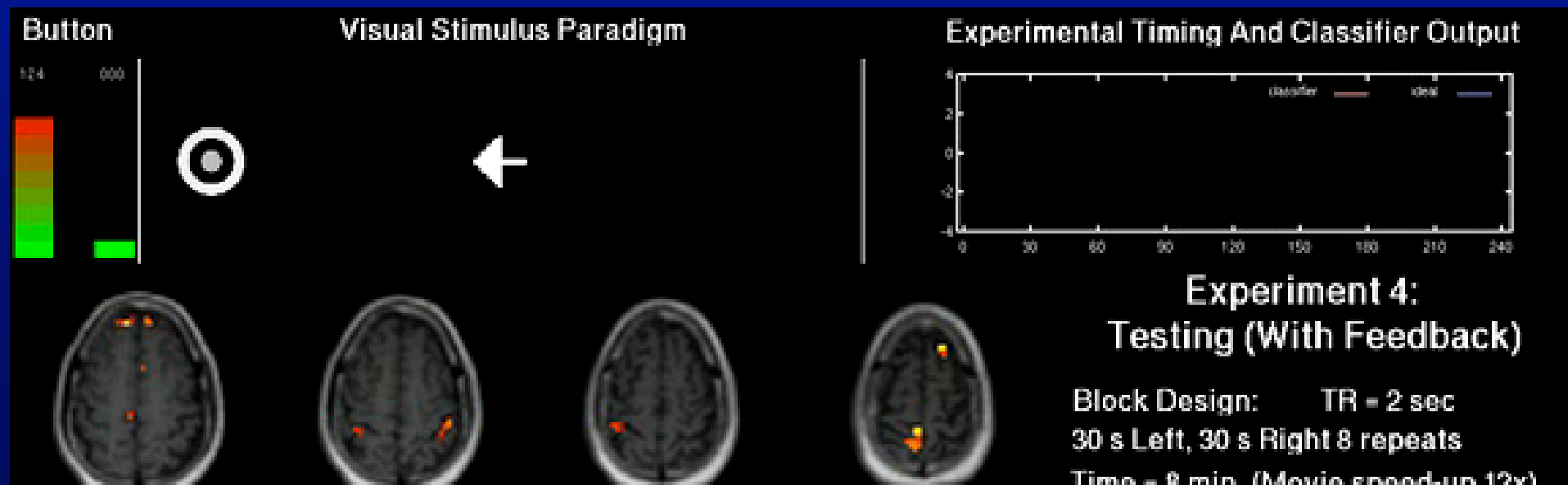
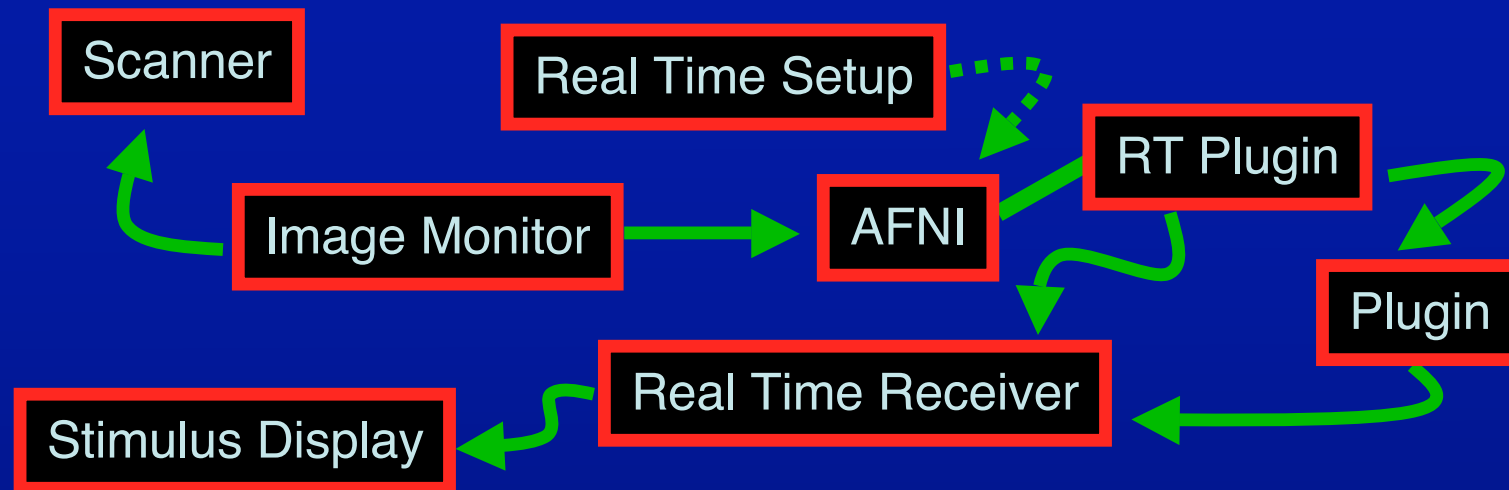
RT SVM plugin*



- SVM plugin is being modified to accept RT data
 - Given training models, classification is done in real-time
 - Classification can go to text, or to Real Time Receiver



Real Time SVM*



*Movie generated with Real Time setup in S. LaConte et al. HBM 2007

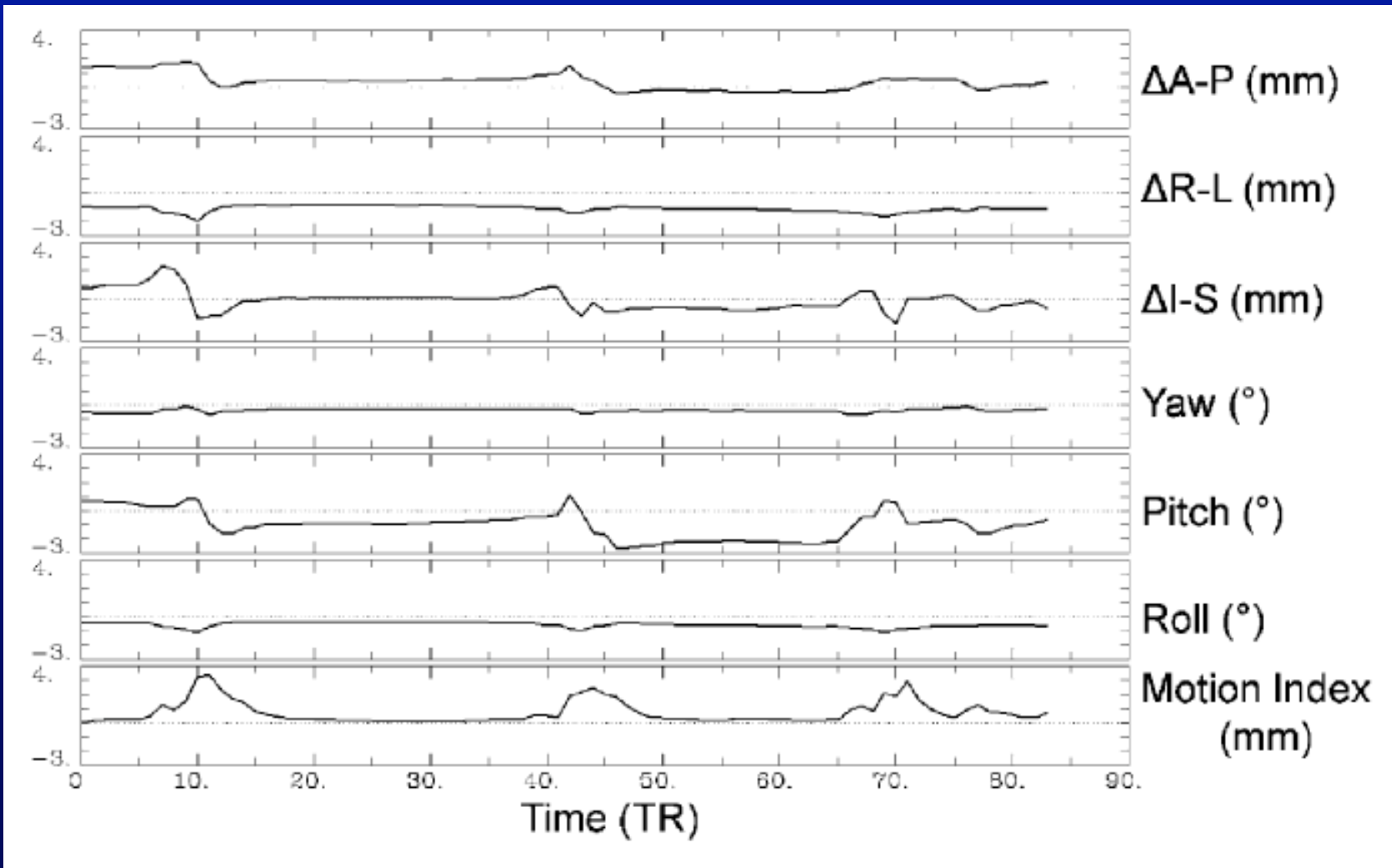
Strategy for Manipulating Activation

- Providing strategy may be critical Adapted from deCharms RC. TCS 07
 - Subjects overestimate ability to control activation
 - Start by providing strategy that activates ROIs regions providing feedback
- See literature on control of various areas
 - Somatomotor cortex From LaConte S. – FMRI Advanced Issues ISMRM 09
 - Posse 2001, Yoo 2002, deCharms 2004, Yoo 2004
 - Parahippocampal place area
 - Weiskopf 2004
 - Amygdala
 - Posse 2003
 - Insular cortex
 - Caria 2007
 - Anterior cingulate cortex
 - Weiskopf 2003, Yoo 2004, Birbaumer 2007, deCharms 2005

Feedback Design

- If incidental to task, minimize interference

Too much information



Feedback Design

- If incidental to task, minimize interference

Enough information

Minimum Task Interference

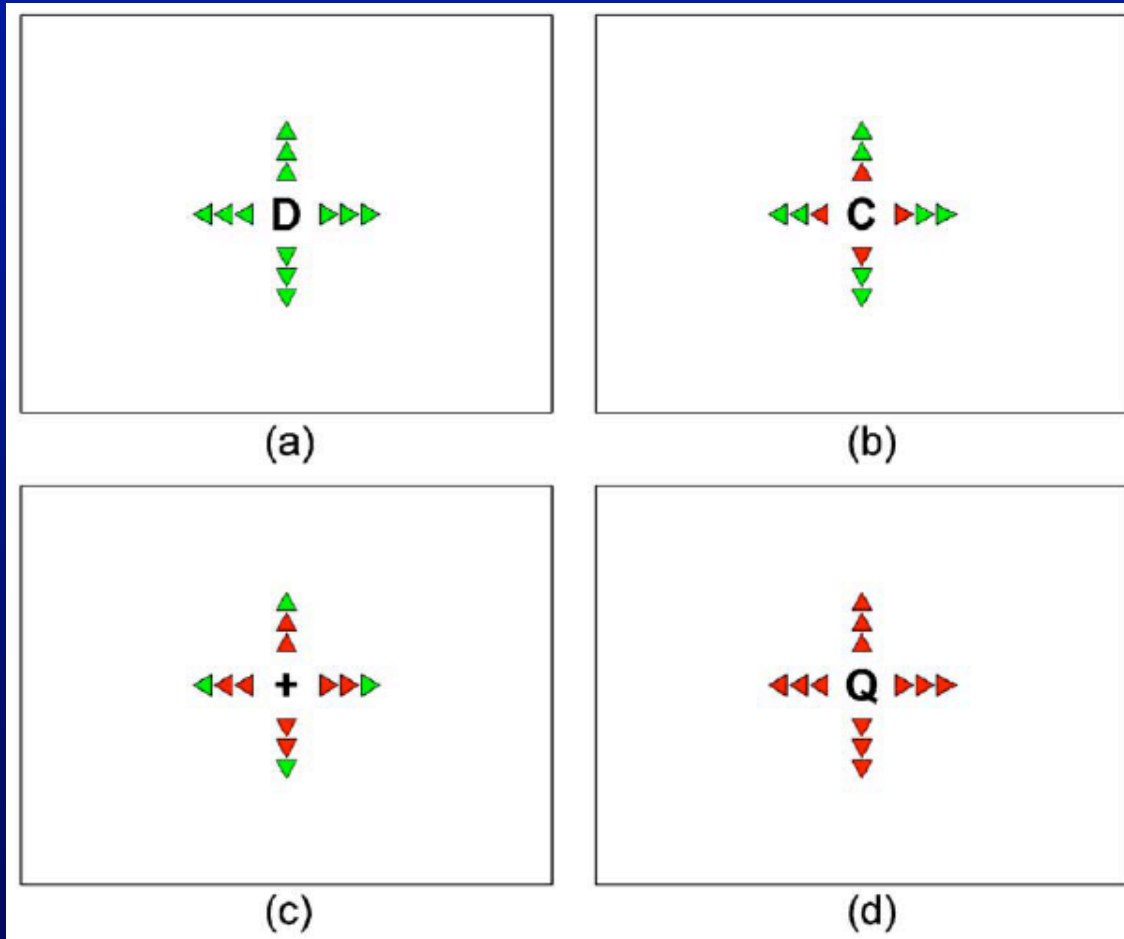


Fig.7 from Yang, S. et al. Neuroimage 05

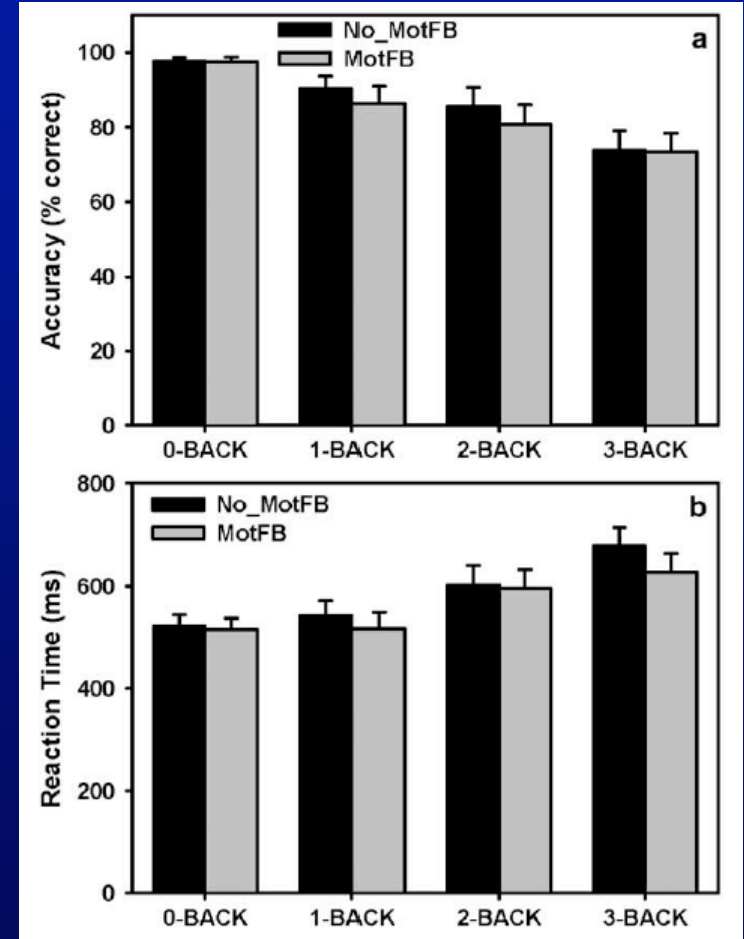


Fig.3 from Yang, S. et al. Neuroimage 05

Feedback Design

- Make it appealing to subject
 - Turns out few get excited about graphs
 - Fire on the beach = much more exciting

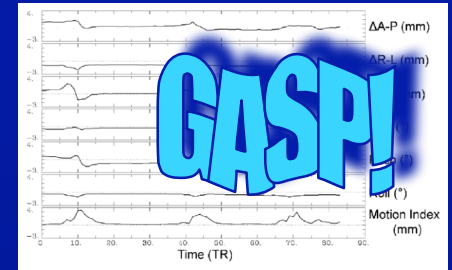
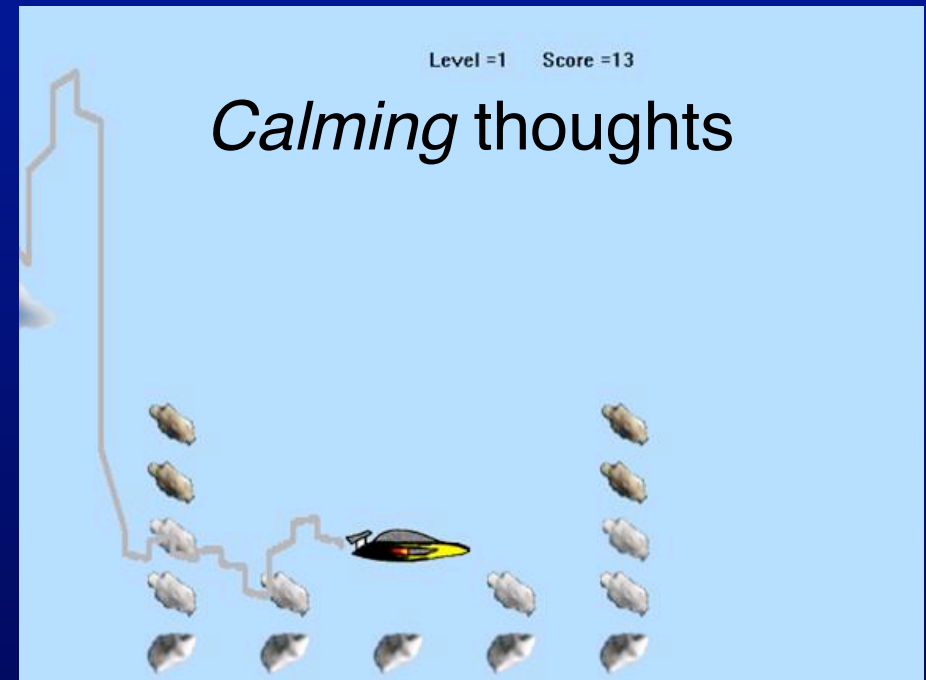


Figure 1d from deCharms RC. Nature 08

Feedback Design

- OMG! Asteroids!
 - Keeps subject interested
 - History trace helps subject cope with fMRI response lag



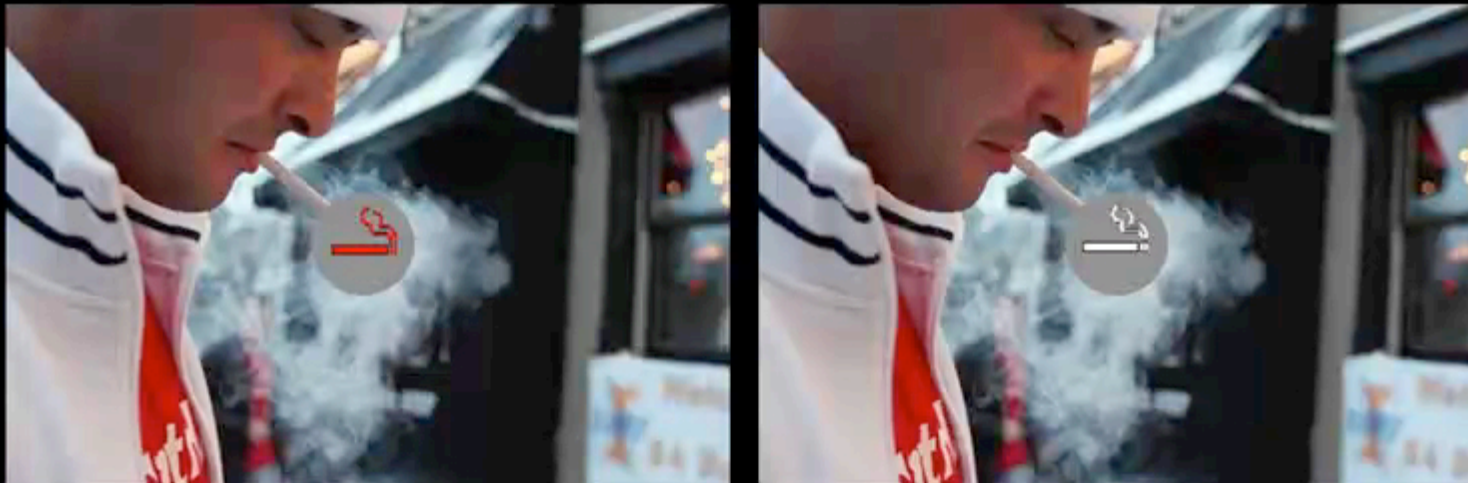
Courtesy of Zhang Y., Kurup P., Ross T. and Stein A.

NIDA/NIH

Z.S.S 8-09

Feedback Design

Interface Design



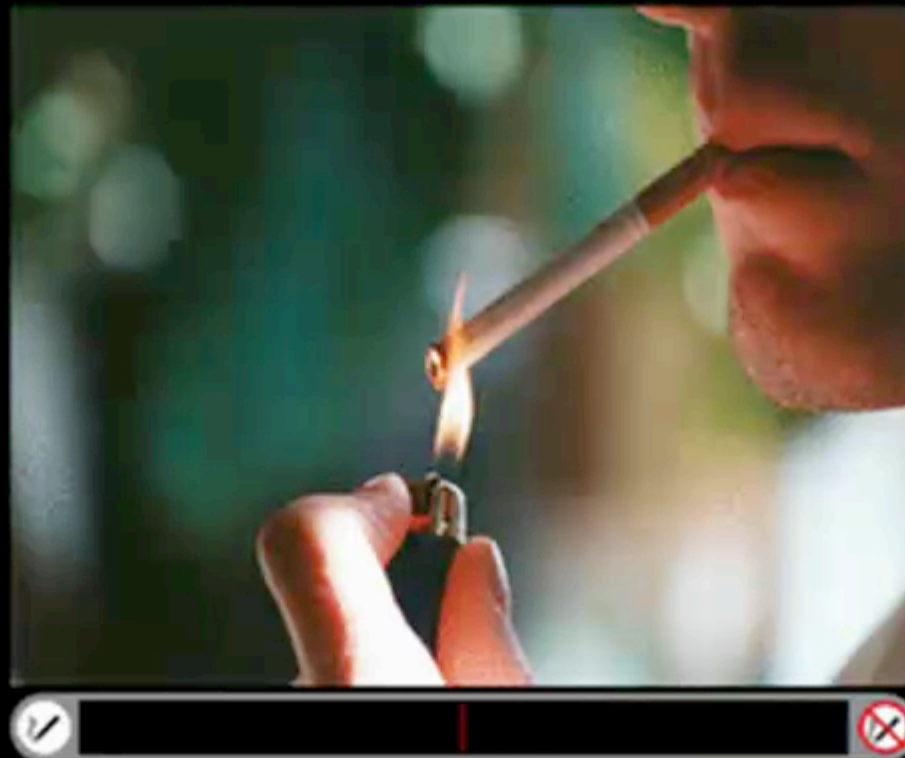
From S. LaConte

ISMRRM 09

Z.S.S 8-09

Feedback Design

Interface Design



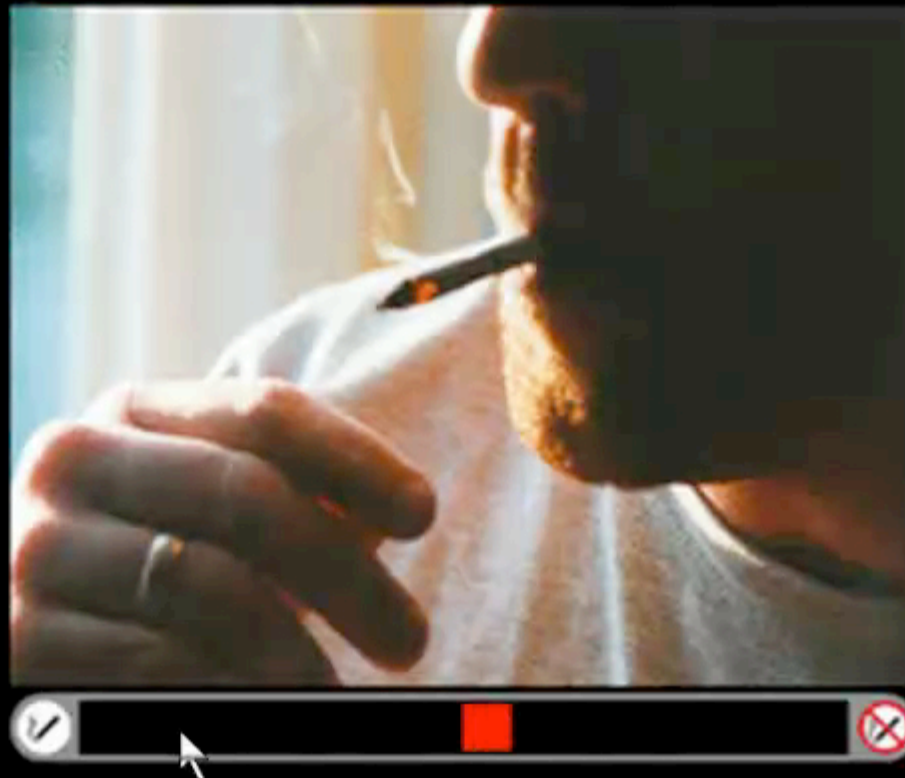
From S. LaConte

ISMRRM 09

Z.S.S 8-09

Feedback Design

Interface Design

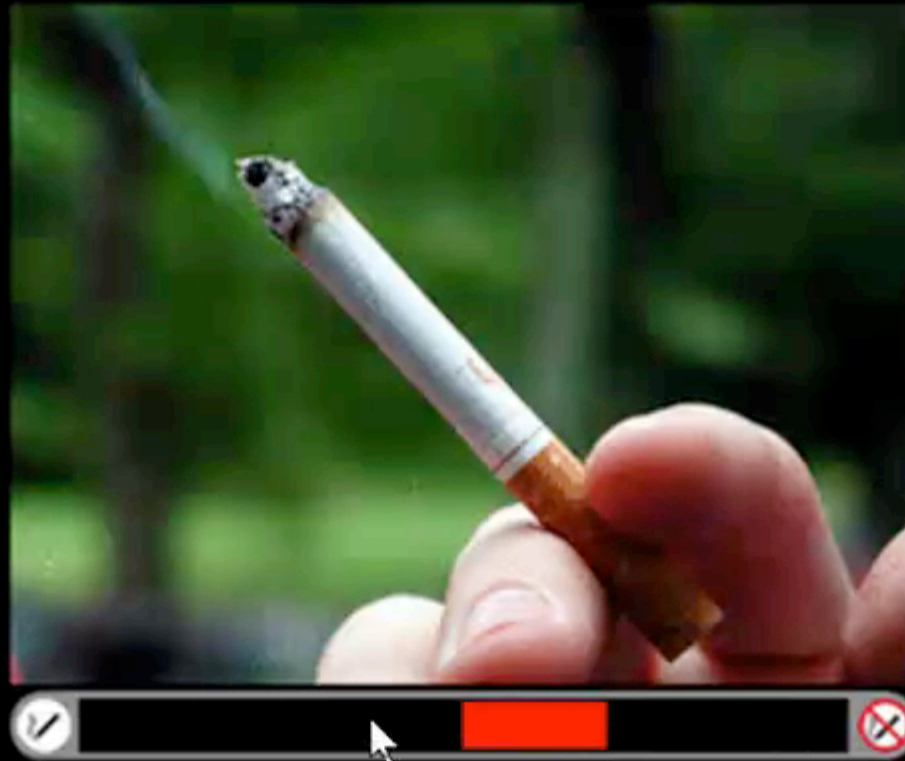


From S. LaConte

ISMRRM 09

Feedback Design

Interface Design



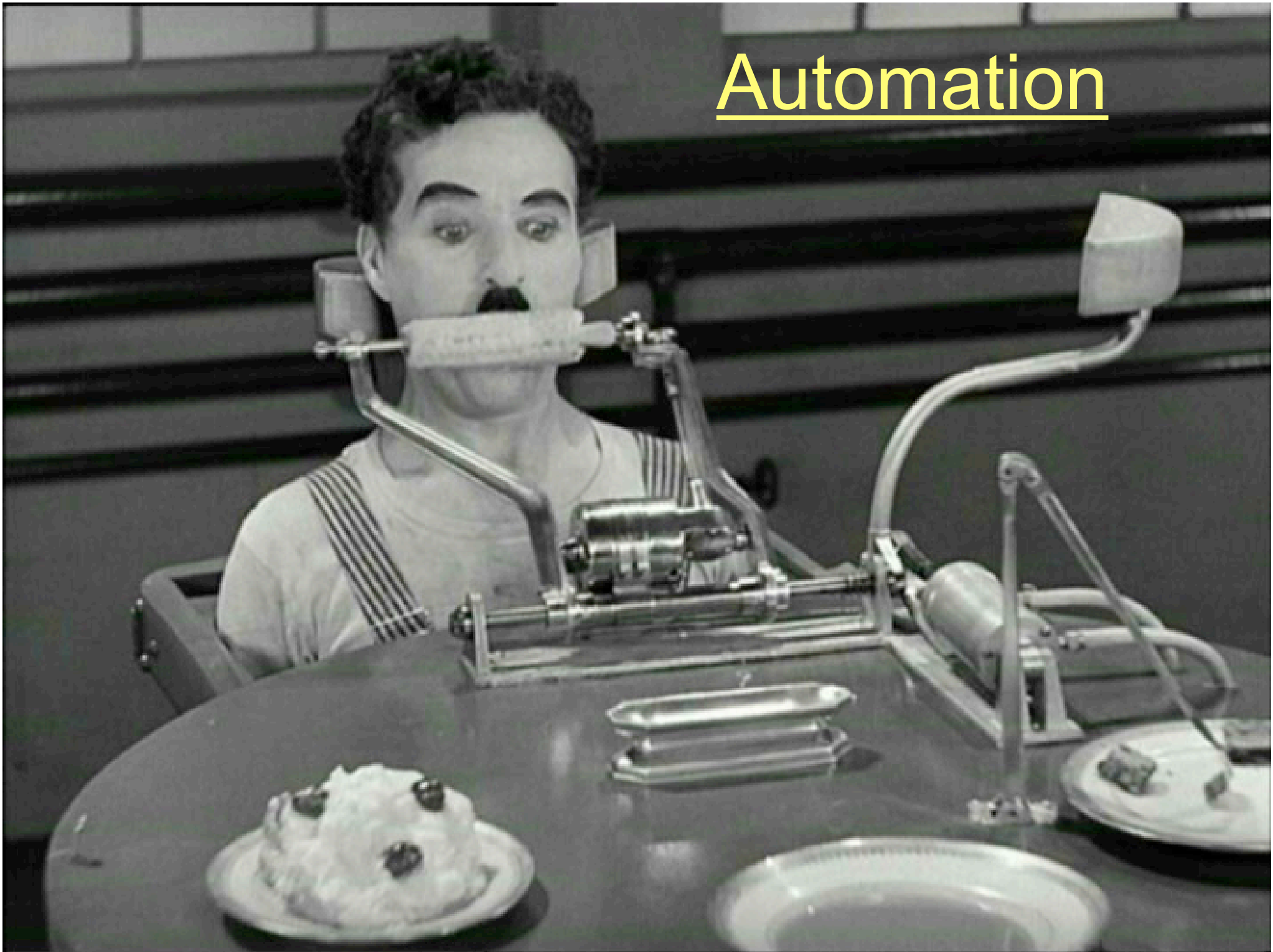
From S. LaConte

ISM RM 09

What to feedback ?

- Which signal to use?
 - From original time series
 - From filtered* time series
 - From regression (Beta/T/R) analysis
- Typically from one or more ROIs
 - Anatomical Atlas based
 - Single subject anatomy based
 - Group function based
 - Single subject localizer
- Combining information from multiple ROIs
 - Encode signals in VR scene deCharms RC. 08
 - Classifiers (ROI or whole brain), if models are known LaConte SM. 07
- What about noise confounds?
 - Control for respiration/cardiac with real-time RETROICOR*
 - Include other physiological covariates in real-time*
 - Include real-time baseline modeling

Automation



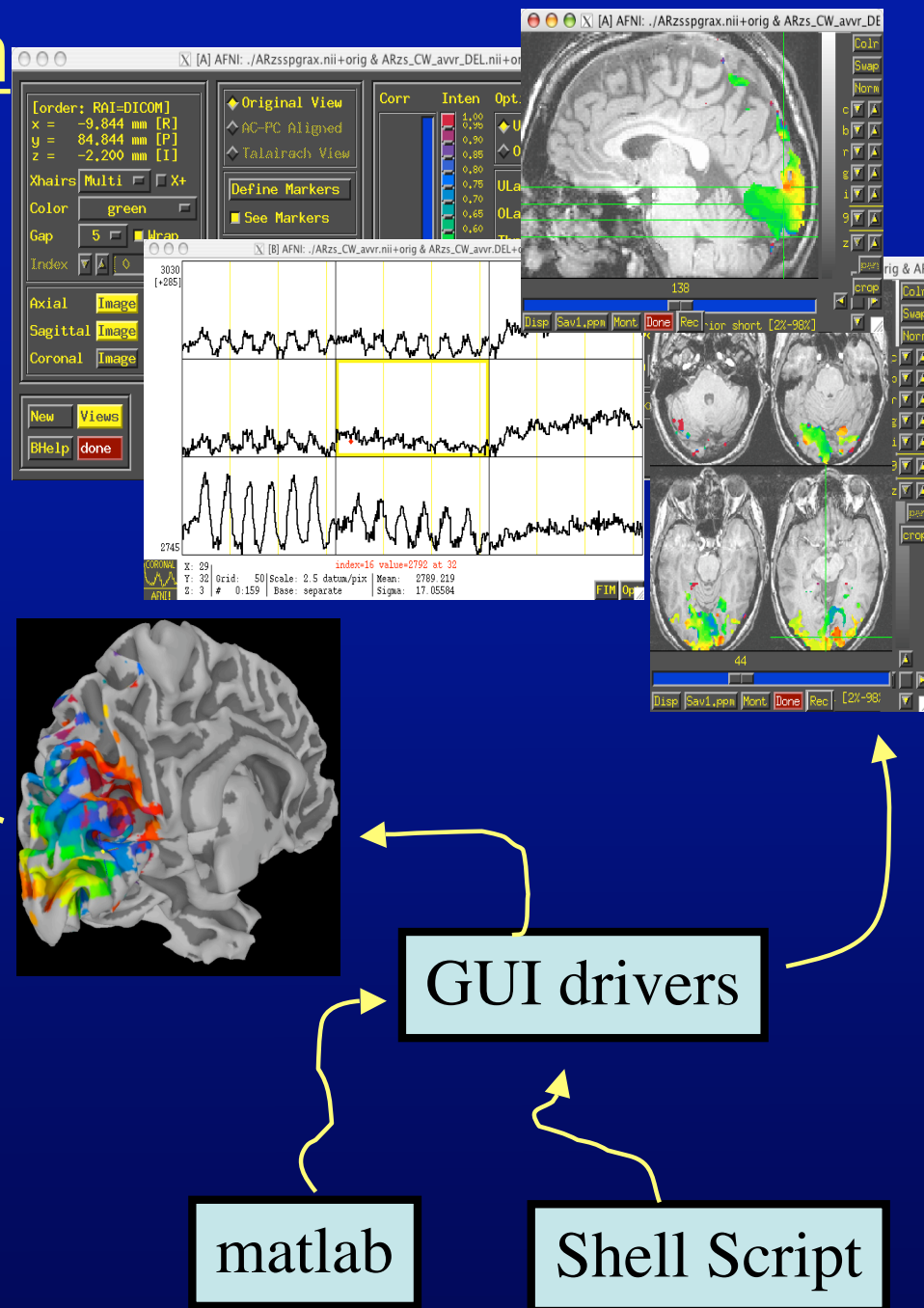
Automating Navigation

Other applications can communicate with AFNI via a program which sends a series of commands for execution.

+ Program called via “system” function (shell invocation)

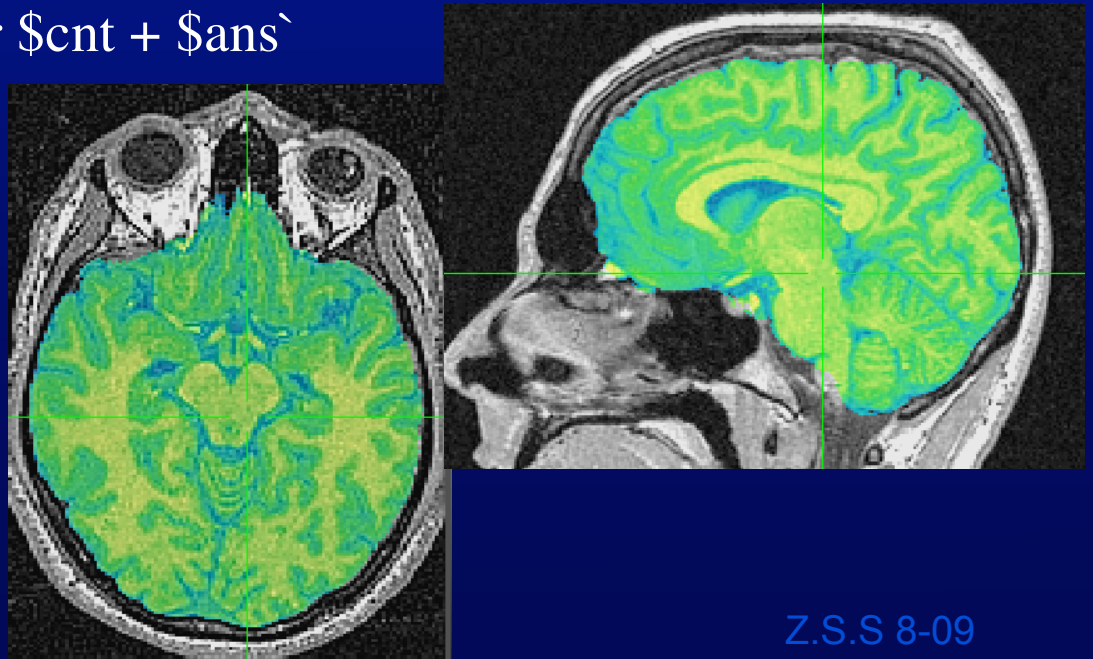
+ No need to manage sockets or format and transmit commands

+ User Interaction with GUI is uninterrupted



Cycling through 300 volumes

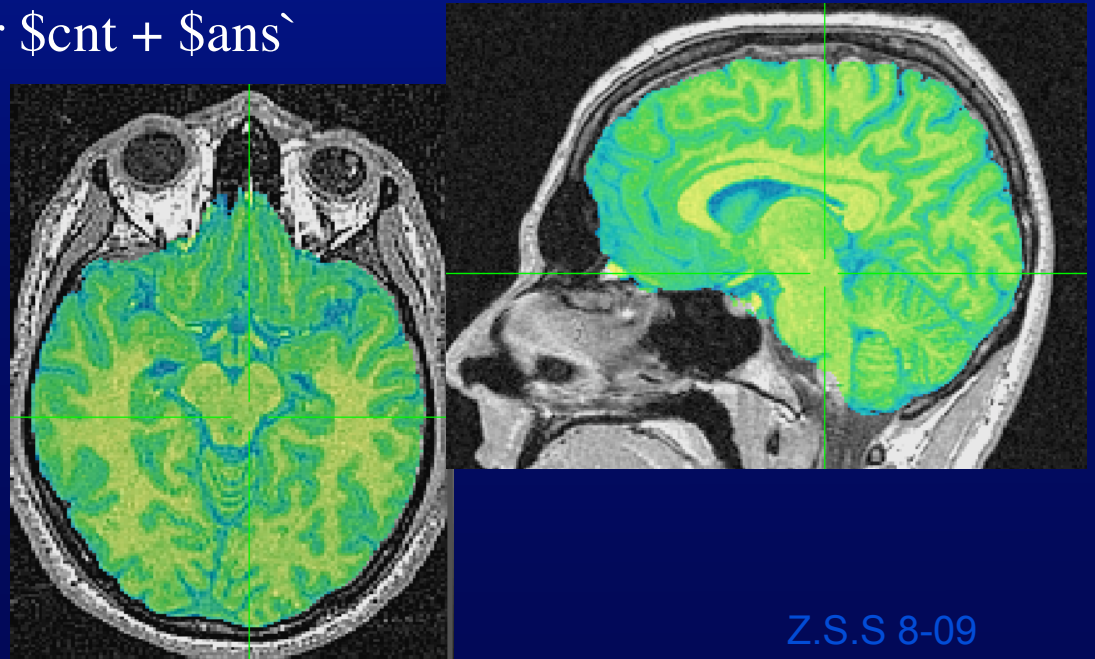
```
while ($cnt < 300)
plugout_drive    -com "SWITCH_UNDERLAY A ${WithSkull[$cnt]}"
                  -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                  -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                  -com 'OPEN_WINDOW A axialimage keypress=v opacity=0.4'
                  -quit
echo "Enter new number or hit enter for next brain:"
set ans = $< && set cnt = `expr $cnt + $ans`
end
```



Cycling through 300 volumes

Loop over all volumes

```
while ($cnt < 300)
  plugout_drive -com "SWITCH_UNDERLAY A ${WithSkull[$cnt]}"
                -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                -com 'OPEN_WINDOW A axialimage keypress=v opacity=0.4'
                -quit
  echo "Enter new number or hit enter for next brain:"
  set ans = $< && set cnt = `expr $cnt + $ans`
end
```

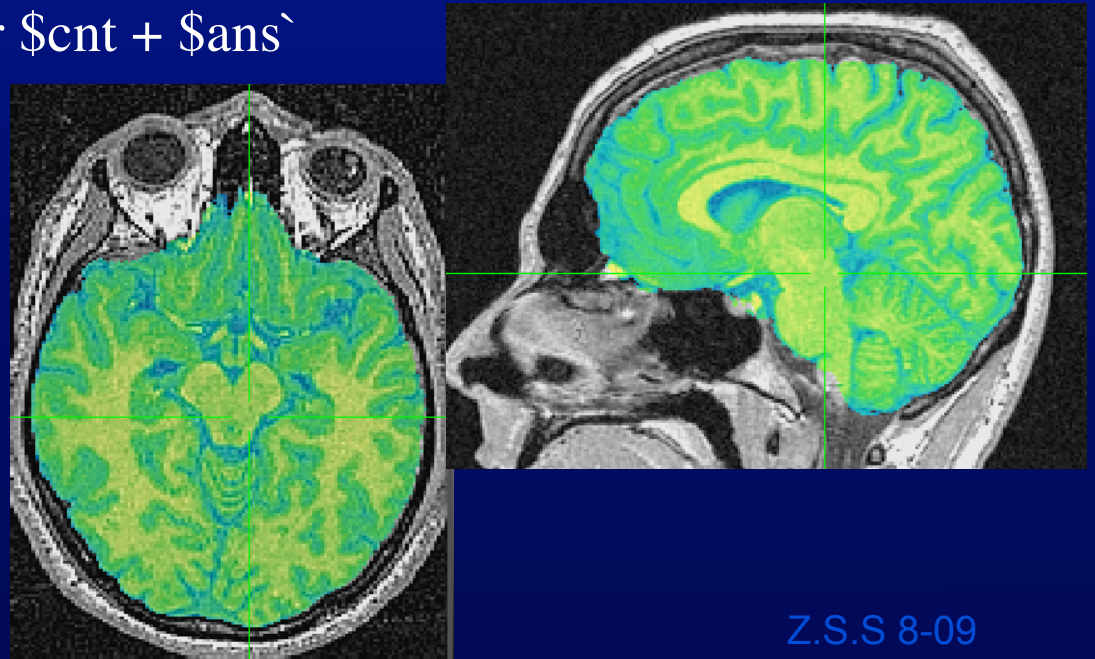


Cycling through 300 volumes

Switch background volume



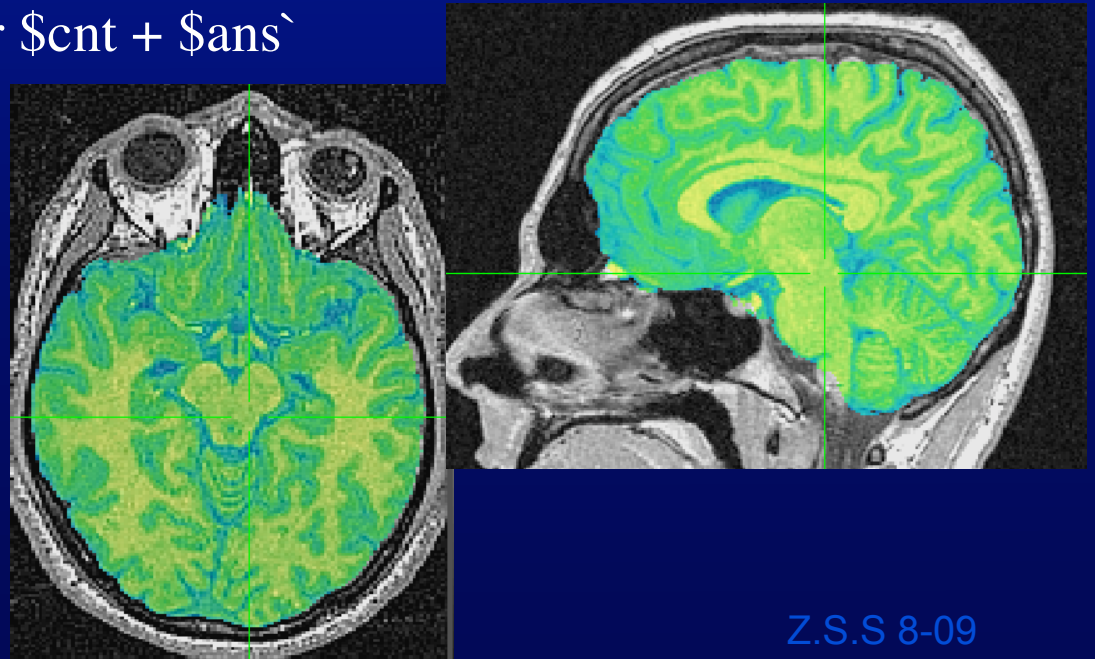
```
while ($cnt < 300)
plugout_drive -com "SWITCH_UNDERLAY A ${WithSkull[$cnt]}"
               -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
               -com 'OPEN_WINDOW A coronalimage opacity=0.5'
               -com 'OPEN_WINDOW A axialimage keypress=v opacity=0.4'
               -quit
echo "Enter new number or hit enter for next brain:"
set ans = $< && set cnt = `expr $cnt + $ans`
end
```



Cycling through 300 volumes

Switch foreground volume

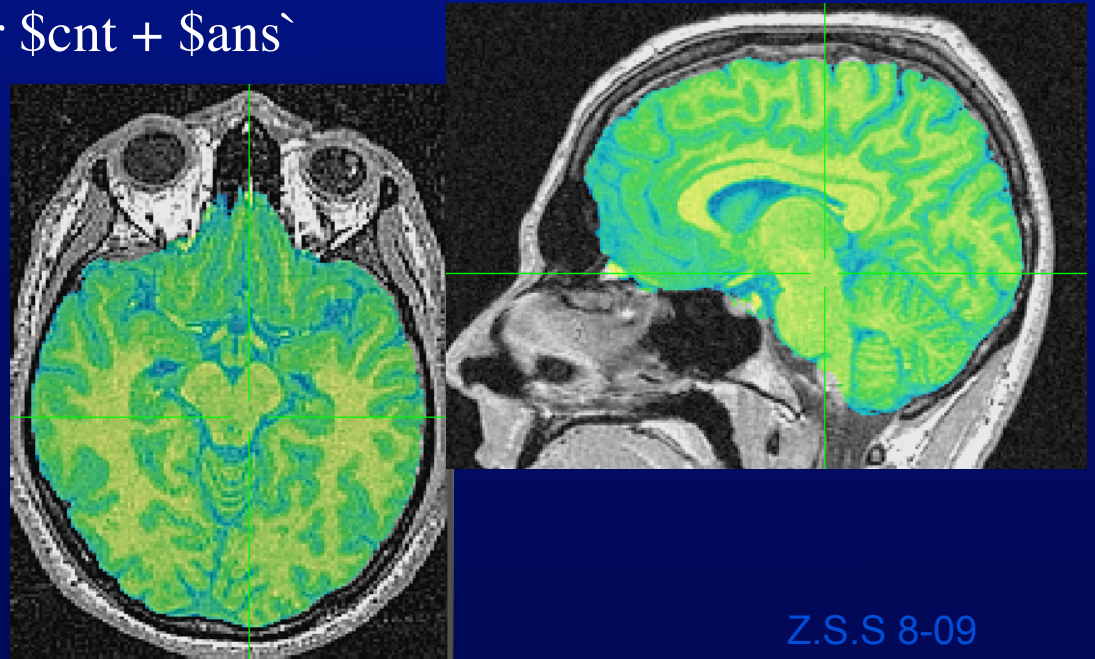
```
while ($cnt < 300)
plugout_drive -com "SWITCH_UNDERLAY A ${WithSkull[$cnt]}"
               -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
               -com 'OPEN_WINDOW A coronalimage opacity=0.5'
               -com 'OPEN_WINDOW A axialimage keypress=v opacity=0.4'
               -quit
echo "Enter new number or hit enter for next brain:"
set ans = $< && set cnt = `expr $cnt + $ans`
end
```



Cycling through 300 volumes

Open coronal image with low opacity

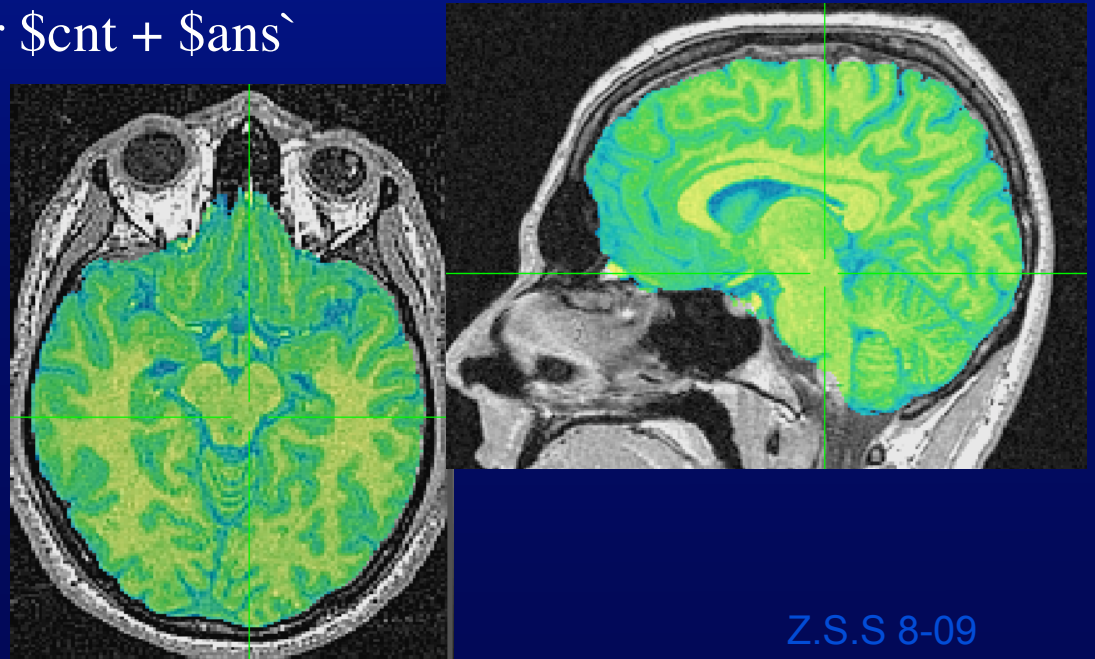
```
while ($cnt < 300)
plugout_drive -com "SWITCH_UNDERLAY A ${WithSkull[$cnt]}"
               -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
               -com 'OPEN_WINDOW A coronalimage opacity=0.5'
               -com 'OPEN_WINDOW A axialimage keypress=v opacity=0.4'
               -quit
echo "Enter new number or hit enter for next brain:"
set ans = $< && set cnt = `expr $cnt + $ans`
end
```



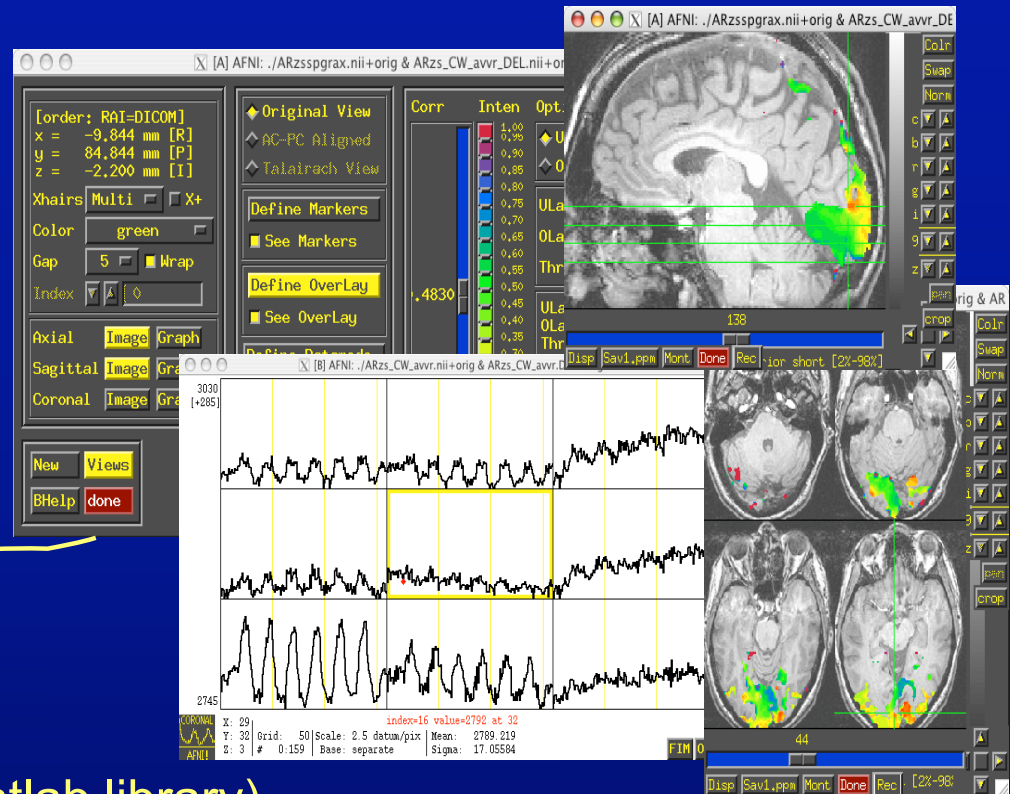
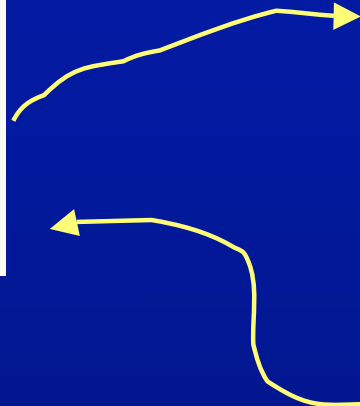
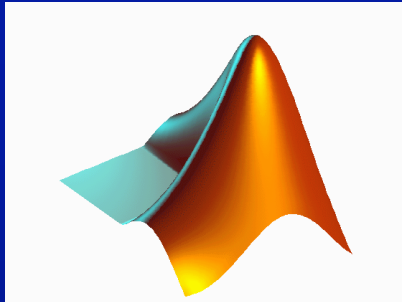
Cycling through 300 volumes

Open axial image and start video mode

```
while ($cnt < 300)
plugout_drive -com "SWITCH_UNDERLAY A ${WithSkull[$cnt]}"
               -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
               -com 'OPEN_WINDOW A coronalimage opacity=0.5'
               -com 'OPEN_WINDOW A axialimage keypress=v opacity=0.4'
               -quit
echo "Enter new number or hit enter for next brain:"
set ans = $< && set cnt = `expr $cnt + $ans`
end
```



Automating Navigation from MATLAB



Excerpts from: Test_TellAfni.m

(Distributed with AFNI's matlab library)

```
cs(1) = NewCs('open_window', '', 'axialimage', 'keypress=""');
cs(2) = NewCs('OPEN_PANEL', '', 'Define_Overlay');
cs(3) = NewCs('Set_Function', 'A', 'ARzs_CW_avvr.DEL');
cs(4) = NewCs('SET_DICOM_XYZ', '', '-6 86 -3');
cs(5) = NewCs('SET_SUBBRICKS', '', '-1 0 2');
cs(6) = NewCs('SET_THRESHNEW', '', 1e-9, '*p');
err = TellAfni(cs);
```

Automation demo

Visual Object Recognition

Lexical Selection

0ms

Phonological Encoding

Phonetic Encoding



"Help" sources

- Readme files
 - README.driver
 - README.environment
 - README.realtime
- Demo material available on:
<http://afni.nimh.nih.gov>
- Automation
 - @DriveAfni script
 - @DriveSuma script
 - @DO.examples
- Sample programs
 - rtfeedme.c
 - Dimon.c
 - serial_helper.c
 - realtime_receiver.py
- Talk to us, we're interested in applications

Acknowledgments

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Thomas Ross



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